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WATER PURIFICATION PLANTS

AND

THEIR OPERATION

BY

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PREFACE

TO THE SECOND EDITION

THE second edition has been made necessary because of the advance and changes which have occurred in the technique of water bacteriology since the book was first published, because of the somewhat different viewpoint as to interpretation of bacteriological tests now held, and in order to incorporate into the instructions for the bacteriological tests certain new details and explanations which it is hoped will lead to better results from these tests in the hands of filtration plant operators.

With these ends in view Chapter IV and parts of Chapter V have been entirely rewritten. It is difficult to adequately cover the interpretation of tests in a limited space and in such a manner as to be available for non-technical men. The treatment may seem somewhat arbitrary, but it is believed that careful reading of the articles on interpretation will convince the trained bacteriologist that they are basically sound and err on the side of safety.

PREFACE

In this book it has been the primary object of the writer to give instructions for the operation of water-purification plants as simply and concisely as is consistent with reasonable completeness. In general, it has been the endeavor to treat the subject with special regard to the requirements of the non-technical operator of small plants, but certain portions have been treated more elaborately, experience seeming to show that graduate chemists have some difficulty in grasping certain phases of the work on first assuming charge of a purification plant. This seems to be especially true as regards the relation of the laboratory work to that of actual operation, the tendency being to neglect the latter and lay undue stress on the former. For the benefit of the non-technical operator it has been attempted to include in one book all information and data required in the operation of the plant, such as instructions for preparing standard solutions, making bacterial and chemical tests of the water, handling coagulants, washing filters, keeping records, etc. For his further aid, charts embracing the computations necessary in determining the amounts of coagulants to be used have been added.

To make the book more readable to those not intimately connected with water-purification plants, a chapter has been added giving detailed descriptions of the various types of plants and their component parts, together with numerous examples. A chapter on the natural chemistry of water has also been added, showing the derivation of its chemical constituents from the geological formations with which it comes in contact.

The writer recognizes that the treatment of water is a very subtle and uncertain branch of applied chemistry, in which every rule has numerous exceptions, and begs to be excused for the rather arbitrary handling of some parts of the subject made necessary to maintain simplicity and clearness to the non-technical reader. For the same reason the products of chemical reactions have been given as definite salts formed, instead of in the more scientific ionic form.

In a book of this kind it is necessary to draw upon many

sources of information, and if the writer has failed to properly acknowledge such source in any case, the omission has been inadvertent. Special acknowledgment is due the United States Geological Survey, from whose reports were obtained considerable data for use in Chapter I, to *The Engineering Record*, to the Transactions of the American Society of Civil Engineers, and to the publications of the American Public Health Association.

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WATER PURIFICATION PLANTS AND THEIR OPERATION

CHAPTER I

WATER AND ITS IMPURITIES

The water obtained from rivers, lakes, wells, and other sources of supply usually contains a considerable quantity of foreign matter in suspension and solution, not only as inert mineral substances, but also in the form of living organisms and waste products of organic origin. From the chemist's standpoint, all of these foreign substances may be considered to be impurities, but in judging a water with regard to its fitness for domestic or industrial use, only those substances which render it detrimental to health, unfit for household and industrial purposes, or unpleasant to the sight, taste, or smell are so considered. In fact, a chemically pure water is rather unpalatable, and experiment and observation seem to show that the presence of certain common mineral substances is desirable in water used for drinking purposes.

The foreign matter generally present in water may be listed as follows:

SUBSTANCES OF MINERAL ORIGIN

In Suspension:
- Clay and Inorganic Soil Wash.

In Pseudo-Solution: *
- Silica
- Alumina
- Iron Oxid

In Solution:

Bicarbonates Carbonates Sulphates Chlorids Nitrates	of	Calcium Magnesium Sodium Potassium
Bicarbonate Sulphates Hydroxid	of Iron	
Mineral Acids		

* Extremely fine particles in suspension.

Dissolved Gases	Carbon Dioxid Oxygen Nitrogen

SUBSTANCES OF ORGANIC ORIGIN

In Suspension:
- Organic Soil Wash
- Decomposing Organic Wastes

In Pseudo-Solution:
- Colloidal Organic Wastes
- Vegetable Color
- Organic Acids

In Solution:
- Vegetable Color
- Organic Acids
- Soluble Organic Wastes
- Ammonia
- Chlorids
- Nitrites
- Nitrates

Dissolved Gases	Carbon Dioxid Hydrogen Hydrogen Sulphid Methane

Living Organisms:
- Algæ, Diatoms, and other plant forms
- Bacteria
- Minute animal forms

This list is neither complete nor rigid in its classification, but presents only the most common substances present in one of a number of possible groupings. The same substances may appear in several groups, as often they may be of either organic or inorganic origin.

To those engaged or interested in water purification, a knowledge of how these impurities and constituents of water are acquired, and of the properties imparted by them to the water, will be of interest and value. It will assist them in better understanding the purposes of water purification, the difficulties and limitations involved in interpreting the results of chemical and bacterial tests, and in adjusting the processes of coagulation and water-softening to the varying conditions of the waters being treated.

Precipitation in the form of rain, snow, dew, etc., is the source of all water supply. Initially this water is pure, being the product of a natural process of distillation, but owing to the remarkable solvent powers of water, it acquires impurities, such as carbonic acid, oxygen, nitrogen, dust, bacteria, etc., even before reaching the ground. After its fall, it is disposed of in three ways. A portion is evaporated from the upper soil and from water surfaces, or, being taken up by plant roots, is transpired through the leaves, and with this we are no further concerned. Of the remainder, called the *runoff*, two dispositions may be made. Part of it flows away over the ground surface to the nearest watercourse and thence to the streams and rivers, constituting the flood flows which follow heavy precipitation or melting snows. The remainder percolates through the soil and only reaches the streams after a more or less lengthy and devious journey through disintegrated, porous, and fissured rock and along impervious strata thereof.

The rain, by the impact of its fall, loosens soil particles from the surface, and carries them to the streams. If the ground is steep, so that the water runs off with high velocity, it will erode the surface, thus adding to the sediment load of the watercourses.

The sediment thus transported to the streams causes the turbid appearance, or *turbidity*, of their waters. This is naturally greatest during floods, when the surface runoff to the streams is much greater than the amount of *ground water* reaching them. Most of the turbidity is derived from plowed fields, from which it follows that in pastured, wooded, or rocky country the rivers are comparatively clear. If a region, however, is composed of steep hills overlain with deep subsoil, this may contribute largely to the turbidity of its streams. Rivers also erode and undercut their banks, which is another contributory source, although most of the sediment so derived is coarse and is deposited as a bar at first opportunity. The first rush of a flood brings with it much *coarse* sediment, but as the flood subsides the sediment carried becomes finer, and is more difficult to remove in the process of purification. In small streams the duration of floods is short, and while the turbidity during high water may be very great, the *average turbidity* is low. Many large rivers are always turbid, due to the almost continuous occurrence of floods on some of their numerous

tributaries, so that in addition to great turbidity during general floods, they have a high average turbidity. The turbidity of a water is measured by comparison with arbitrary standards, made by adding definite amounts of especially prepared powdered silica or fuller's earth to bottles of distilled water, as explained in detail in Chapter III. The results are stated in *parts per million.* Thus if one part by weight of the powdered silica is uniformly mixed (by shaking in a bottle) with one million parts of perfectly clear distilled water, the resulting turbidity of the standard thus prepared is said to be one part per million, and a sample of water which on comparison with this standard presents a similar appearance, is said to have the same turbidity. Results obtained with different waters are not strictly comparable, being affected by variations in the color, composition, and relative fineness of the suspended matters. A turbidity of five parts per million is barely discernible; a turbidity of 100 gives a water a very cloudy appearance; a water with a turbidity of 1,000 is practically opaque in appearance. During floods the turbidity of a stream may rise above 10,000 parts per million, and under varying conditions values may occur from this down to zero.

The portion of the runoff which percolates through the soil absorbs carbonic and traces of other acids from the decaying vegetable matter contained therein, and from the excretion of plant roots. The acidity thus obtained enhances its power of solution, and enables it to attack mineral matters which would otherwise prove insoluble. During the passage through the soil much of the oxygen absorbed by the water from the air is removed therefrom by the decaying organic matter. This enables the water to hold in solution certain salts which would be oxidized to an insoluble condition were oxygen present. After descending through the soil and subsoil, the water enters the rock strata or glacial drift composing the upper geological formation of the region. In the more ancient formations, the rocks consist of granite, basalt, gneiss, etc., of which mixed silicates of aluminum and potassium, sodium, calcium, or magnesium are the principal constituents; the mineral *felspar*, a mixed silicate of sodium or potassium and aluminum, being very prominent. The carbonic-acid-charged water leaches the alkalies and alkaline earths from these rocks and removes them in solution as bicarbonates, thereby reducing the hard, resistent strata to soft, clay-like substances

which can be dug with a spade. The action of the carbonic acid and water on felspar $(KAl\ Si_3O_8)_2$ is typical of this process:

$$(KAlSi_3O_8)_2 + CO_2 + 2H_2O = K_2CO_3 + H_2Al_2(SiO_4)_2H_2O + 4\,SiO_2$$

Felspar + Carbonic Acid = Potassium Carbonate + Kaolin + Silica. The potassium carbonate and silica are carried off by the water in solution, the latter in colloidal form. The kaolin remains behind as clayey surface soil. The proportion of sodium and potassium silicates to those of calcium and magnesium in this class of rocks is such that the resulting ground water is high in alkaline carbonates and low in the bicarbonates of the alkaline earths.* It results that such ground waters are characterized as *soft,* although of relatively high *alkalinity.* The presence of these alkaline carbonates makes possible the acquisition and retention by the water of considerable quantities of silica (SiO_2), alumina (Al_2O_3), and iron oxid (Fe_2O_3) as a suspension of extremely fine particles, a state known as *colloidal solution.* In this colloidal state, these substances do not readily enter into chemical reaction, and are difficult to remove by filtration. While they cannot be said to add to the turbidity of a water, they may give to it an opaque appearance due to the reflection of light by the particles.

The waters from a region underlain by ancient formations of igneous rock (or more recent formations in volcanic districts) of the kind above described are sometimes called *primary* waters, in reference to the position of these rocks in geologic history. Such waters are characterized by the proportionately (although not necessarily quantitatively) large concentration of salts of the alkalies (sodium and potassium) and the small amounts of salts of calcium and magnesium present, and further by the presence of silica and alumina (iron to a less extent) in the colloidal state.

Although it has been computed that silicates of the above types constitute 98 per cent of the earth's crust for the first 10-mile depth, yet large areas are overlain with *secondary* or derivative rocks. Often these take the shape of horizontal strata, evidently deposited by sedimentation or biologic growths at a time when the

* Sodium, potassium, and certain less common chemical elements are known as the metals of the *alkalies.* Calcium, magnesium, and certain less common elements having similar properties are known as the metals of the *alkaline earths.* The presence of both alkaline and alkaline earths compounds contributes to the property of water called "alkalinity," while only the alkaline earths compounds contribute toward the property of "hardness."

land was submerged beneath the sea. Such formations are the limestones, dolomite (mixed calcium and magnesium carbonate), sandstones, and shales, which form the great central valley of the United States, as well as the more localized beds of salts (sodium, calcium, and magnesium chlorids), gypsum (calcium sulphate), etc. Again, large areas are deeply covered by *till* formed of finely comminuted rock material interpersed with bowlders, which has resulted from glacial action. In the northern United States a large sheet of this material exists, covering roughly the Dakotas, Minnesota, Wisconsin, Michigan, Iowa, Illinois, Indiana, most of New York, New England and part of Ohio, Nebraska, Kansas, and Missouri. In part it consists of gravels, sand, and clay, but contains much ground-up limestone and dolomite, so that it may be said to act the same as strata of these toward the percolating water, the resulting ground water being high in bicarbonates of calcium and magnesium.

The water passing through such secondary formations dissolves the carbonates present by virtue of its contained carbonic acid, and removes them as bicarbonates. Thus in the case of calcium and magnesium carbonates the reaction is:

$$CaCO_3 + H_2CO_3 = CaCO_3,H_2CO_3$$
$$MgCO_3 + H_2CO_3 = MgCO_3,H_2CO_3$$

These bicarbonates give to a water the property of *temporary hardness*, so called because, by heating, the carbonic acid is driven off, and the normal carbonates are precipitated.

The existence of large deposits of salt and gypsum has been mentioned. Water passing through such formations acquires considerable amounts of these compounds as sodium and calcium chlorids ($NaCl$ and $CaCl_2$), and as calcium sulphate ($CaSO_4$), respectively. Magnesium sulphate ($MgSO_4$) is also acquired in this way. These render the water *permanently hard*, *i.e.*, the hardness cannot be removed by ordinary boiling. A stream may also have its chlorid content increased by the discharges from oil and brine wells, and, if near the sea, by salt spray carried inland on the winds. Decomposing organic matter is another source of chlorids in water. Most limestones contain small amounts of calcium sulphate, so that it is quite generally found in *secondary* waters.

If an alkaline stream mingles with one containing sulphates

and chlorids of calcium and magnesium, a softening reaction results quite similar to the artificial process, with the formation of sulphates and chlorids of sodium and potassium, and the precipitation of calcium and magnesium as carbonates or their retention as bicarbonates, according to the following equations:

$$\left.\begin{matrix} CaSO_4 \\ MgSO_4 \end{matrix}\right\} + 2Na_2CO_3 = \left\{\begin{matrix} CaCO_3 \\ MgCO_3 \end{matrix}\right\} + 2Na_2SO_4$$

$$\left.\begin{matrix} CaCl_2 \\ MgCl_2 \end{matrix}\right\} + 2Na_2CO_3 = \left\{\begin{matrix} CaCO_3 \\ MgCO_3 \end{matrix}\right\} + 4NaCl$$

This accounts for the large amounts of sodium sulphate sometimes found in primary waters.

Traces of the nitrates of alkalies and alkaline earths exist in various rocks, and these find their way into the water and enter into reactions in a manner quite similar to the sulphates and chlorids.

Iron is quite abundant and almost universally distributed, occurring in most rock formations, and especially in gravels and sands, which often have a distinct yellow or reddish discoloration as a result. It occurs most commonly as hematite (Fe_2O_3). As has been stated, water is often deprived of its oxygen by decaying organic matter, in passing through the soil. In this condition it will, if it comes in contact with iron oxid, remove from the latter part of the oxygen, leaving it as ferrous oxid (FeO). This ferrous oxid combines with the carbonic acid in the water to form the soluble ferrous bicarbonate ($Fe(HCO_3)_2$), which is carried off in solution. Many waters contain a trace of iron in this form. When a badly polluted stream devoid of oxygen flows over or percolates through a gravel bed, or when the underflow of such a stream is tapped by means of wells, the water becomes so highly charged with iron as to become unusable. Similarly a subterranean supply drawn from a gravel bed is usually high in iron. On standing, exposed to the air, an iron-containing water will become turbid, due to the oxidation of the iron, which is changed to the insoluble ferric hydroxid ($Fe(OH)_3$). The iron bacterium, Crenothrix, subsists on the soluble ferrous carbonate and changes it into an insoluble ferric state, leaving it in the water as a stringy, gelatinous precipitate. This bacterium grows with-

out light, consequently thrives in covered reservoirs, water mains, and the like. Iron sulphate occurs in mine waters and will be discussed later.

Of the gases contained in water, the most common are carbonic acid (CO_2), oxygen, and nitrogen. The former is derived from the air, from decaying vegetation and plant excretion in the soil, and from decaying organic matter in lakes, swamps, and quiescent bodies of water generally. Oxygen is derived mainly from the air. These gases are acquired from the air quite rapidly, so that if the water is for any reason depleted, a fresh supply is soon obtained. There is some question as to how this repletion takes place. In event of wave action, rapids, or cascades, the method is, plainly enough, one of mechanical mixture, followed by the solution of the gases in the water. In the case of quiet bodies of water, the process is less plain. It is contended by some that the gases are dissolved in the surface water by contact, and pass into the interior of the water by *diffusion,* which is the tendency of soluble bodies in solution so to distribute through the solvent that the concentration will be uniform throughout. Thus, a gas dissolved in the surface of a liquid would distribute itself throughout the body thereof so as to bring about a uniform distribution of the gas particles. This theory is opposed with much validity by the contention that the rate of diffusion is too slow to account for the rapid replenishment which actually occurs. The opponents advance the theory of "streaming action," according to which evaporation from the surface layer concentrates the impurities in it, causing it to become of higher specific gravity than the water below, and to sink, carrying down the occluded gases obtained by contact with the air. In lakes and swamps abounding in plant life a balanced relation between carbonic acid and oxygen has been found to exist. During the growing season, carbonic acid is absorbed by the plants, and oxygen is given off, causing the water to be high in oxygen and deficient in carbonic acid. During the dormant period of plant life the reverse is true. Plants will first use up the *free* carbonic acid in the water, and thereafter the *half-bound* carbonic acid, which is in loose combination as the bicarbonates of calcium and magnesium, causing these to precipitate as normal carbonates. It follows that during the growing season, the alkalinity and temporary hardness of the water are reduced. The presence of a trace of carbonic-acid gas seems to render water

more palatable, probably because it is a natural content of normal waters.

All normal waters contain oxygen in considerable concentration, usually over 50 per cent of the saturation value, and it is only deficient in waters polluted by putrescible organic matter, or containing oxidizable mineral matter (such as mine drainage). Waters not charged with sufficient oxygen give off disagreeable odors and will not support fish life, and are shunned as water supplies.

Nitrogen is absorbed from the air in the same manner as oxygen, but is an inert gas chemically. Methane (marsh gas) is found in swamp water, due to decayed vegetation. Hydrogen sulphid is found in presence of decaying organic matter and in some deep well waters. The last two gases are conspicuous because of the unpleasant taste and odor which they impart to the water. They can be removed to a large extent by aeration.

The saturation value of all gases in water varies with the temperature. Table I shows these variations for oxygen, from which it is seen that the concentration increases with lower temperatures.

TABLE I*

QUANTITIES OF DISSOLVED OXYGEN IN PARTS PER MILLION BY WEIGHT IN WATER SATURATED WITH AIR AT THE TEMPERATURE GIVEN

Temp. C.	Oxygen	Temp. C.	Oxygen	Temp. C.	Oxygen
0	14.70	11	11.05	21	9.01
1	14.28	12	10.80	22	8.84
2	13.88	13	10.57	23	8.67
3	13.50	14	10.35	24	8.51
4	13.14	15	10.14	25	8.35
5	12.80	16	9.94	26	8.19
6	12.47	17	9.75	27	8.03
7	12.16	18	9.56	28	7.88
8	11.86	19	9.37	29	7.74
9	11.58	20	9.19	30	7.60
10	11.31				

* Standard Methods of Water Analysis—American Public Health Association.

As has been said, the water in a stream is of two components—the surface runoff and the ground-water supply. The first component furnishes the flood flows and the turbidity, the second feeds the stream uniformly with a mineralized water, consequently supplies the low-water flow of the stream almost entirely. It

results that during high water the mineral content of the water is low while during low water it is high. Furthermore, the *underflow* of a stream generally carries more dissolved mineral matter than the surface flow. During floods the carbonic acid and organic matter in the water may increase, due to flushing out of back-channels, stagnant pools, and swamps.

Water from streams draining areas of primary rock, sand, or other resistant material are very often colored. This is not due to turbidity, which gives to water an *apparent* color depending on the kind of sediment carried, but to coloring matter in solution, which cannot be removed by ordinary filtration. This coloring matter is derived from decaying vegetable matter in swamps, or from muck and peat beds. It consists generally of tannates, gallates, and organic acids from the leaves and bark of shrubs and plants. Turbid waters are not generally colored, since the clay carried as sediment is partly in the colloidal state and has the power of removing color by the process of *adsorption*, by which the colloidal particles draw the color into themselves, as a sponge does water. The efficacy of this process depends upon the type of clay constituting the turbidity, impure clays being best.

Thus far, only the properties of normal or natural waters have been considered. In some cases industrial wastes modify or completely change the character of streams. Most notably is this the case with streams receiving mine drainage, especially from coal mines. Coal contains sulphur in the form of calcium sulphate, as iron pyrites (FeS_2), and probably in organic form. This is discharged in the mine drainage as sulphuric acid (H_2SO_4) and ferrous sulphate ($FeSO_4$).

On reaching the stream, the ferrous sulphate is oxidized by the oxygen contained in the water, forming ferric hydroxid, which settles out, and ferric sulphate, which remains in solution:

$$6FeSO_4 + 3O + 3H_2O = 2Fe_2(SO_4)_3 + Fe_2(OH)_6$$

$$Fe_2(OH)_6 = Fe_2O_3 + 3H_2O$$

The rate of oxidation is partly dependent on the replenishment of the air supply in the water. Under the most favorable conditions of oxygen supply the process consumes several days, so that water in mining regions may contain sulphuric acid and both ferrous and ferric sulphates. As limestones are present in coal-bearing formations, the normal streams of such regions would contain bicarbonates of calcium and magnesium, but the iron sulphates

and sulphuric acid react with these, and calcium and magnesium sulphates result, together with iron carbonate, which, if sufficient oxygen is present, is precipitated as hydroxid. Thus a mine water will contain the constituents of permanent hardness, and, with increasing mine-drainage factor, ferrous and ferric sulphate and finally sulphuric acid. Where the mine drainage is of recent addition paucity of oxygen and the presence of *ferrous* carbonate will be noticeable.

The most objectionable property of water containing mine drainage is its corrosiveness. The iron sulphates and acid will actively attack metals. A limited quantity of ferric sulphate, once admitted into a boiler or other closed metallic water container, will attack the same unintermittently. The ferric sulphate will dissolve sufficient iron to reduce itself to the ferrous condition, and being oxidized by the air admitted with fresh water, will again attack the boiler, and by continuous repetitions of this process will accomplish its early ruin. Brass piping, plumbing fixtures, etc., are eaten away, and even "acid-proof" bronze is not immune. Other objectionable qualities are the taste imparted and discoloration in laundry work. In the stream itself the lack of dissolved oxygen is harmful and often prohibitive to fish life, but no bad odors are caused by decomposing organic matter, as should be expected in deoxidized water, because the iron sulphates precipitate organic matter as non-putrefactive compounds. Such waters are comparatively free from bacteria, which cannot live under very acid conditions. If, however, the exposure to acid water is short, they may form spores. It thus sometimes happens during the purification of acid water that the raw water seems sterile, but when treated with lime and settled, numerous colonies of bacteria appear, due to development of the spores under favorable alkaline conditions. Acid water will cause sediment in suspension to coagulate, so that in a turbid stream, on entering a mining region, the suspended matter will collect in clots, and later settle out, leaving the water clear. Should a stream containing ferrous sulphate mingle with one high in color, due to vegetable tannates and gallates, the water will become black, due to the formation of natural ink.*

While mine drainage is the most important industrial waste in

* Proc. Eng. Soc. Western Penna., Vol. XXVII, No. 8.

changing the character of streams, other wastes may have a marked but more localized effect. Drainage from salt and oil wells may so pollute a stream, especially if small, as to render it unfit for use, and even large rivers may acquire a briny taste from this source. About 250 parts per million of chlorine will give water a salty taste. The salt further deposits in boilers, forming scale. Tannery waste imparts a color to the water, and, due to acids present, has a germicidal effect, although not generally strong enough to kill the spores. Paper-mill waste consists partly of vegetable organic matter and of spent acid and bleach liquors. Other sources of pollution are dye works, steel mills (pickling acids), slaughter-houses, and breweries. The last two may have an important influence where a water supply is obtained from wells in alluvial drift. They impart much organic matter to the water, whose putrefaction deprives it of oxygen, so that the water in percolating through the alluvial gravel becomes very highly charged with iron, and unfit for use.

Sewage from towns and cities is an important source of pollution, particularly because through it such diseases as typhoid fever, cholera, etc., are disseminated. The sewage contains much nitrogenous organic matter in solid (finely divided) and colloidal states and in solution, as well as large numbers of sewage bacteria (which may average 3,000,000 per cubic centimeter and more). Through the agency of some of these bacteria, the organic matter absorbs the dissolved oxygen from the water of the stream into which the sewage discharges, and is oxidized, with the production of carbonic acid, water, and salts of nitrogen. Other bacteria attack the solid and colloidal organic matter, reducing it to solution, and by a process of fermentation break it up into ammonia, hydrogen and hydrogen sulphid, nitrogen, and marsh gas. By further oxidation, the ammonia is changed to nitrites and, finally, to stable nitrates. Physically, sewage pollution may impart to the water a turbid appearance varying with large amounts from milky white to almost black, according to the amount of putrescible matter; strong odors, due to putrefaction; and innumerable bacteria. Chemically, it is evidenced by the scarcity of dissolved oxygen and by the presence of ammonia, carbonic acid, nitrites and nitrates. The indicative tests are those for *albuminoid ammonia* (due to very recent pollution and the presence of unoxidized nitrogenous matter), *free ammonia* (evidence of partially

decomposed sewage, and, consequently, more remote pollution), nitrites, and nitrates, the final decomposition products in stable inorganic form. Sewage is high in chlorine, but this passes unchanged through the various stages of putrefaction and affords no reliable evidence of the time of pollution.

The living world is largely represented in natural water. Of plant forms, besides such higher plants as water lilies, water ferns, etc., there is a large representation of free floating types, the group *Thallophytes* being most prominent. This group has two great divisions *Algæ* and *Fungi*. In the first division are included the masses of green floating filaments, blue-green algæ (Cyanophyceæ), so commonly seen in ponds and reservoirs, which impart grassy odors to the water, and the pond scum, or green algæ (Chlorophyceæ). Also the minute, one-celled plant forms (diatoms), which may be either free-swimming (having the power of motion) or attached by gelatinous stalks, and which give off strong odors, especially in the spring and fall. The peculiarity of the Algæ is their ability to subsist on inorganic matter, being true plants. The Fungi, however, are parasitic, and can only live on organic matter. Such are water molds and bacteria (Schizomycetes).

Bacteria are microscopic, one-celled fungi, which generally have the power of motion. They are very numerous in water, and derived from several sources. Many species are indigenous to water; others are soil bacteria which have been washed into the stream, and these predominate during floods and in turbid waters. Sewage contributes others, each cubic centimeter containing many millions. Most bacteria in the water are harmless or beneficial, assisting in the decomposition of organic matter, but some species contained in sewage are very harmful, being capable of producing disease, if the water is used for drinking purposes. These diseases are mainly intestinal in character, and are transmitted by the discharges of patients entering streams as part of the sewage, the bacteria being disseminated through the water, which is drunk by other persons further down stream. The most common are typhoid fever, cholera, dysentery, diarrhœa, and other intestinal disturbances. The bacteria of these diseases do not grow or multiply in the water, which acts simply as a carrier. They are, in fact, very difficult to discover or isolate in a water supply, but there exists a group of bacteria, the *Coli* bacilli, which flourish only in the

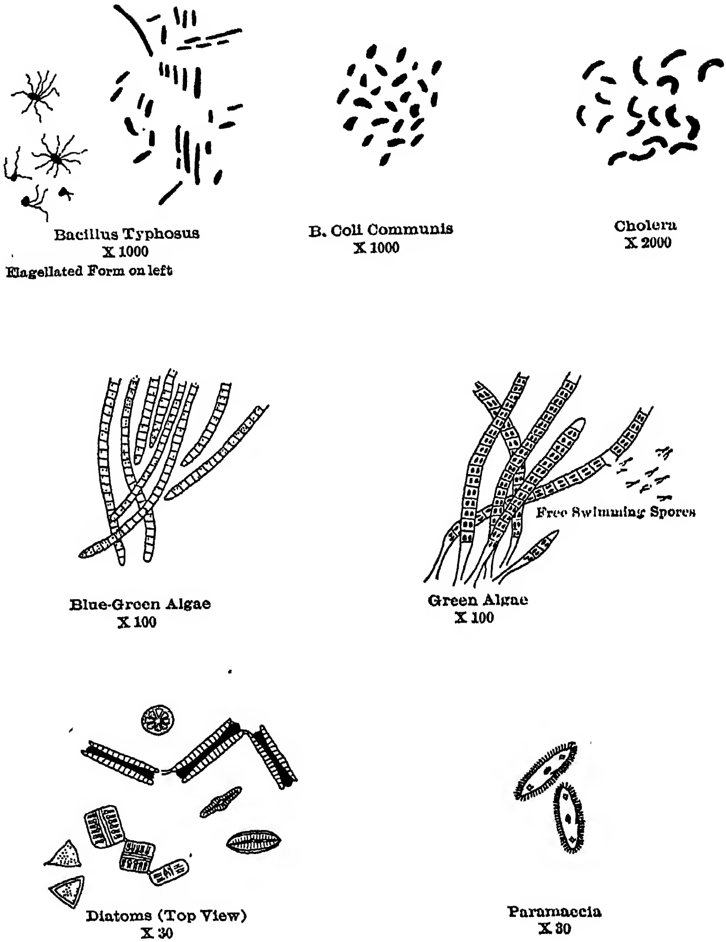

FIG. 1.—Microscopic Life in Water. The number below each group indicates the degree of magnification.

intestines of man and higher animals,* are readily detected and identified, and are therefore considered indicative of human or animal pollution. Their evidence has great sanitary value, as a water receiving human excreta may at any time receive that of a sufferer from typhoid or other intestinal diseases.

As to the representatives of animal life, besides fish and the higher forms there are, among others, fresh-water sponges (Spongidæ), minute, free-swimming shrimp-like forms (Crustacea), and Protozoa. The last are microscopic unicelled animalcules, which seem quite closely related to bacteria in form and habits. Both sponges and protozoa may cause tastes and odors in water.

As this discussion of the properties of water has been, in the main, *qualitative*, it may be well in closing to give a few quantitative examples of water types, so that the reader may form an idea of the proportions in which the various constituents exist:

TABLE II

TYPICAL WATERS: ANALYSES IN PART PER MILLION

Compounds	A	B	C	D	E
Sodium Sulphate	6	9	6	4	16
Potassium Sulphate	2	....	....	....	3
Calcium Sulphate	....	....	57	68	78
Magnesium Sulphate	....	....	....	....	33
Iron Sulphate	....	....	....	....	12
Sulphuric Acid	....	....	....	....	40
Sodium and Potassium Chlorid	4	5	8	51	7
Calcium Chlorid	....	....	....	23	....
Sodium and Potassium Nitrate	1	4	7	6	2
Sodium and Potassium Carbonate	6	....	....	....	....
Bicarbonate of Iron	2	2	1	1	....
Sodium and Potassium Bicarbonate	15	....	....	....	....
Calcium Bicarbonate	25	130	170	117	....
Magnesium Bicarbonate	11	49	135	96	....
Silica	28	15	17	17	9
Alumina	....	....	....	....	8

A. Stream flowing through primary formation. The carbonates and bicarbonates of the alkalies are high, those of the alkaline earths low. The water received some calcium and magnesium sulphate, which reacted with the alkaline carbonates to form alkaline sulphates, with a corresponding increase in the

* For a modification of this statement, see page 141.

bicarbonates of the alkaline earths. Note the high silica content (in colloidal state).

B. Typical secondary stream, from limestone formation. The principal constituents are alkaline earth bicarbonates. A small amount of alkaline carbonates was present, as well as some calcium or magnesium sulphate, which by interaction formed sodium sulphate and alkaline earth bicarbonates. In this water all hardness is temporary and equals the total alkalinity.

C. Stream high in calcium sulphate (permanent hardness). This water is characterized by permanent hardness and a high magnesium content.

D. Stream high in chlorids. Polluted by salt wells or mines.

E. A stream badly polluted by mine water. This was normally a water of type C, although lower in bicarbonates, but has been entirely changed in character by the action of iron sulphate and sulphuric acid from mine drainage, almost all constituents being converted into sulphates. An extension of the analysis to dissolved gases would probably show much carbonic acid and a deficiency of oxygen. The alumina in solution is characteristic of such waters.

Note in all the analyses: (*a*) the uniformity of the chlorids (except, of course, in D); (*b*) the uniformity of nitrates, iron (except in E), and silica (except in A), suggesting that these constituents are more or less equally distributed through all geological formations and are sluggish chemically in the form present.

Fig. 2 shows a map of the United States on which the geological formations are very broadly indicated. The principal primary formations are in the Appalachians, the northern part of Wisconsin and Minnesota, and the great mountain region of the West. A large area of central and northern United States, roughly that portion north of the Missouri and Ohio Rivers, is deeply covered with glacial drift, which in some cases consists of ground-up local rock, and in others of materials transported hundreds of miles from their original locations. Some of this material has also been carried south of the area of glaciation by prehistoric torrents, and by the rivers and winds. Streams in this glaciated region derive many of their mineral qualities from the leaching of this drift. The limestone formation occuring in Missouri, Kentucky, southern Ohio, Tennessee, Alabama, and Georgia is also indicated. The

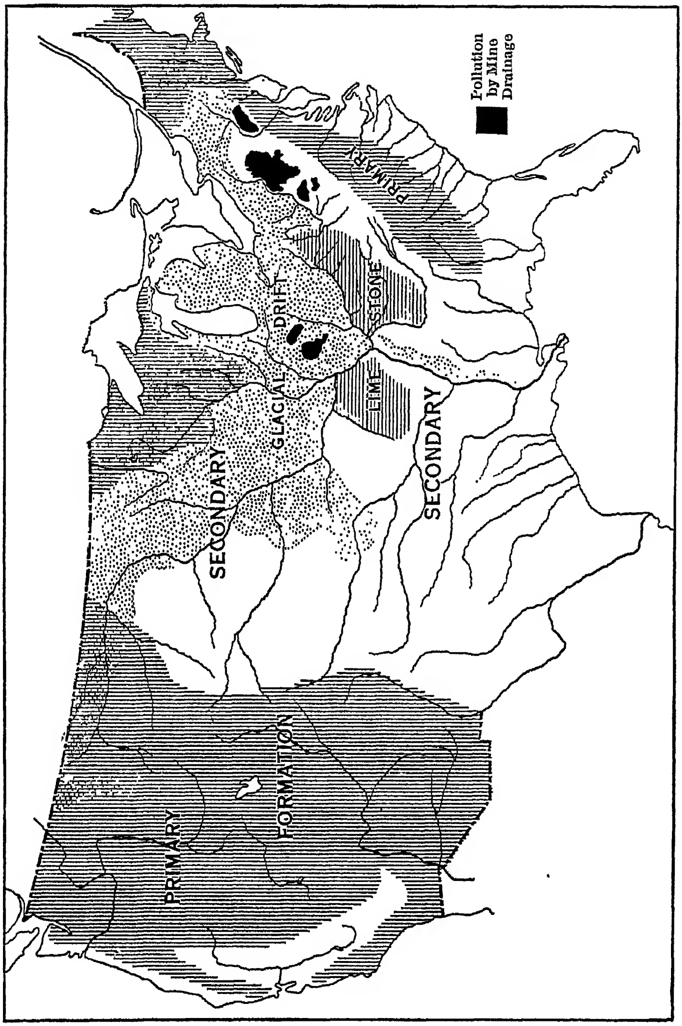

FIG. 2.—Map to Illustrate how Geologic Formations Influence the Properties of Water.

streams of this formation are notoriously hard, and require softening for economical use. Areas polluted by mine drainage are shown in black. The map illustrates the heterogeneous chemical contents to be expected in large rivers. Thus the Missouri originates in an area of primary rocks, later flows through a region of secondary or derivative formation, receiving also its quota of hard water from limestone beds. This map is submitted to illustrate broadly the principles involved and makes no pretense at great accuracy or detail.

CHAPTER II

TYPES OF PURIFICATION PLANTS

THE objects of water purification may be briefly stated as follows:

1. To render the water safe and harmless for drinking and domestic use. This involves the almost complete removal of bacteria, in order to be sure that all pathogenic (disease-producing) species are eliminated.
2. To make the water *inviting* and *pleasing* in appearance and taste. This requires:
   (*a*) The removal of suspended matter.
   (*b*) The removal of odors and tastes.
   (*c*) The elimination of dissolved color.
   (*d*) The removal or oxidation of organic matter.
   (*e*) The removal of iron.
3. Improving the water for industrial and household use by:
   (*a*) Reducing the hardness (temporary and permanent).
   (*b*) Eliminating iron in solution.
   (*c*) Neutralizing acids (such as sulphuric and carbonic).

Any or all of these objects are attainable by means of a properly designed and operated purification plant to a degree sufficient to meet all requirements. It is possible to remove over 99 per cent of the bacteria regularly, and by sterilization the removal may be made practically complete. It is hardly necessary to say that this has a marked effect on the reduction of water-borne diseases, but it may be well to call attention to Fig. 3, showing the death-rate from typhoid fever in Columbus, Ohio,* for the last ten years, during five of which the water was filtered. Filtering has reduced the death-rate from an average of about 75 per 100,000 to about 17 per 100,000 per year. The reduction in typhoid fever is further shown by the following table, compiled by Mr. Allen Hazen:

* Compiled by Charles P. Hoover, Chemist in Charge of Filtration Plant, Columbus, O.

TABLE III

ANNUAL AVERAGE DEATH-RATES FROM TYPHOID FEVER BEFORE AND AFTER FILTRATION

City	Extent of Record		Typhoid Death-Rates per 100,000	
	Years Before	Years After	Before	After
Binghamton, N. Y.	5	5	47	15
Cincinnati, O.	4	4	50	12
Columbus, O.	11	4	78	11
Hoboken, N. J.	7	6	19	14
Paterson, N. J.	5	9	32	10
Watertown, N. Y.	5	7	100	32
York, Pa.	2	12	76	21
Albany, N. Y.*	9	9	74	22
Lawrence, Mass.*	7	15	114	25
Washington, D. C.*	5	6	57	33

* Slow sand filters.
From Hazen, in International Congress of Demography and Hygiene, 1912.

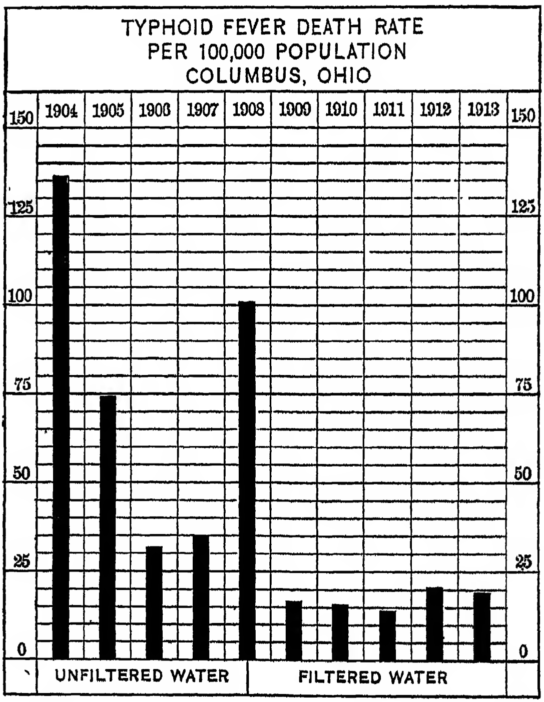

FIG. 3.—An Example of the Decrease in Typhoid Fever Death-Rate Following Filtration of the Water Supply.

Suspended matter can be completely removed; odors, tastes, and color can be greatly reduced. Hardness can be reduced to the residuum due to dissolved carbonates, and the same may be said of acids, if the treatment is carried far enough. Iron and organic matter can be brought down to negligible quantities.

The processes of water purification finding practical application for municipal purposes are:

(*a*) Coagulation and sedimentation.
(*b*) Slow sand filtration.
(*c*) Rapid sand or mechanical filtration.

To these might be added filtration through natural sand beds, possible only under exceptional geological conditions, and various experimental methods of unproven value.

Coagulation and Sedimentation. Coagulation and sedimentation is used to some extent in purifying the turbid river waters of the Middle West, and has found its most successful application at St. Louis, Mo.,* and a number of other municipalities situated on the Missouri River. It requires coagulating apparatus and facilities of the kind described in connection with mechanical filtration, and large settling basins, of from one to three days' capacity.

The coagulants used are generally ferrous sulphate and lime, owing to their comparative cheapness and the high specific gravity of the coagulum formed. As the waters thus treated are very turbid, large amounts of coagulants are required, and for the same reason the question of organic coloring matter, a delicate subject in connection with the iron-lime treatment, is eliminated.† Alum and lime as coagulants have also been used in this process.

The settling basins are similar to those described in connection with mechanical filtration, except in respect to size. Needless to say, the study of proper baffling in order to prevent short-circuiting or currents is of utmost importance in this case. It is not likely that this process will find extensive use in the future, as mechanical filtration has proven to be more effective and economical. The general tendency is toward supplementing with filtration such plants as are now in operation.

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* The process at St. Louis has been supplemented by mechanical filtration.
† See page 243.

The data and charts in this book apply with equal force to this process, as does also much of the matter in the last chapter, despite the title thereof.

Slow Sand Filtration. This process is of English origin, and dates from about 1830. From England it was disseminated throughout the Continent, where it is now widely used. In America it has found extended use in the older installations and in the purification of the supplies of large cities, although of recent years the mechanical process has become an important competitor in plants of large size, and has far outstripped it in the case of supplies for smaller towns.

Description of Plant. A general view of a typical slow sand filtration plant is shown by Fig. 4. It consists of duplicate sedimentation basins *d-d*, the filter units *g-g-g*, the office and laboratory *e*, and various auxiliaries.

The water is drawn from the river through the intake *a*, and pumped to the sedimentation basins by low-service pumps in the station *b*, entering the basins through a distributing grid of pipe which may terminate in the aerating risers *c-c-c*, to remove obnoxious gases from the water, and distribute it uniformly across the basins. It is sometimes desirable with turbid waters to use coagulants to assist in clarification, in which case the necessary apparatus, similar to that used in mechanical filtration, is installed in the building *e*, which is enlarged for that purpose and for coagulant storage. The size of the basins is dependent on the amount and fineness of sediment in the raw water, the period of sedimentation being generally from four to twelve hours. In filtering clear lake water, where the removal of bacteria is the main object, the sedimentation basins may be omitted entirely.

After passing through the basins the water is collected by the inlets of the pipe manifold at the lower end, which is connected with the settled water main extending through the *court* between the two rows of filters. Branches from this main lead to each filter, terminating within the filter in a float valve which maintains a uniform depth of water over the sand.

Each filter consists of a water-tight basin of masonry or reinforced concrete, generally roofed over with a groined arch construction supported on columns, the whole being covered with several feet of soil and sodded, as an additional protection against freezing of the water, which materially affects the efficiency of

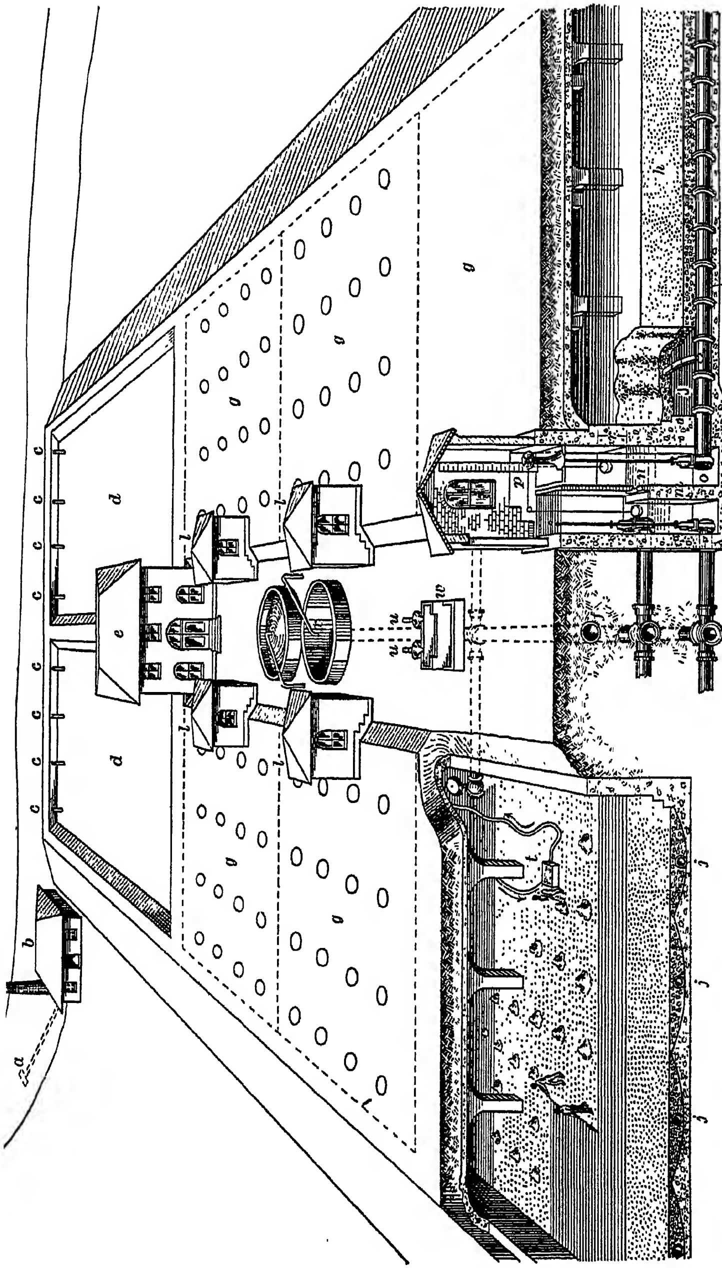

FIG. 4.—General View of a Slow Sand Filter Plant.

filtration. Covering the filter also prevents the formation of algæ, by excluding the light necessary for their growth. Access to the interior is provided by an inclined runway and by numerous double-covered manholes in the roof, which also furnish the necessary light and ventilation for carrying on work in the filter. The area of these filter units is from one-fourth to one acre or more, depending on the total capacity of the plant.

The filtering medium consists of a bed of clean quartz sand *h*, of a size of grain approximating that of granulated sugar. In technical terms it has an *effective size* * of about 0.3 to 0.4 millimeters and a *uniformity* † coefficient of about 1.5. The depth of sand bed is generally from 3 to 4 feet in a new filter, decreasing as the dirty sand is scraped off with continued use. This sand is underlain with a foot of gravel *i*, so graded as to increase in coarseness toward the bottom. The function of this gravel is to prevent the sand from being washed into the collector system with the filtered water, and to allow ample water passages through which the filtrate can flow to the collecting pipes. Open-jointed tile pipes *j*, from 4 to 8 inches in size, rest on the filter bottom, buried in and surrounded by the gravel. Generally one such collector pipe serves the area between two adjacent rows of columns, and carries the filtered water to the main collector *k*, which is placed through the center of the filter unit.

It is most important that the filtration proceed at a uniform rate, and to this end each filter unit is provided with a regulator house *l*, the lower portion of which forms a water-tight well containing the regulation mechanism. The arrangement shown, used in the Albany plant by Mr. Allen Hazen, will illustrate the general principle of regulation, although not of the most recent type. It does not profess to operate automatically, and therefore will better serve to emphasize the attention required to maintain a uniform rate of filtration, even by more recent "automatic" types. The well is divided into two parts by a concrete diaphragm *m*, and by tight wooden stop planks above the diaphragm. The filtrate, collected by the main *k*, flows into the first compartment of the well through the valve *o*, rising therein to a height lower than the

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* The *effective size* of a sand is that size of sand grain than which 90 per cent of the grains are larger.

† The *uniformity coefficient* is the ratio of the size of sand grain than which 60 per cent is finer, to the effective size.

water level over the sand by a distance r, representing the friction of the water through the sand, gravel, and under-drain system or "loss of head" through the filter. The water flows through the orifice n into the second compartment of the well, and thence through a valved branch pipe to the main s, which carries the effluent of all the units to the filtered or "clear" water basin, ready for delivery into the distribution system. The rate of flow through the orifice n is a function of the difference in water level between the two compartments of the well when the orifice is submerged, and a function of the water level in the first compartment when that in the second is below the bottom of the orifice. By arranging a float in each compartment so as to indicate this difference in water level on a dial, the rate of filtration may be determined from the reading of the dial, and can be regulated to the desired amount by means of the graduated valve o. Two other floats, similarly arranged, indicate the loss of head through the filter. A valve and drain pipe are provided, leading to a main drain for emptying the filter.

Rate and Loss of Head. The rate of filtration varies from 2,000,000 to 6,000,000 gallons per acre per day, 3,000,000 gallons being very commonly used. The rate used at any plant should be varied as experience dictates, the controlling elements being the quality of effluent, which will deteriorate with too high rates, and the period between cleaning the filters, which will shorten under the same conditions, and may become so frequent as to prove uneconomical. The head of water required to force the water through the filter at the determined rate is measured by the loss-of-head gage. For any given rate of filtration the loss of head increases with the length of time the filter is in operation, due to the deposits of silt formed on and in the filter sand, which greatly augment the friction through same, until finally the head of water would become sufficient to break down the resistance of the sand, causing unfiltered water to find its way into the collector mains. At a safe interval before this occurs, the filter must be shut down and either raked or cleaned by scraping. This maximum loss of head may be conservatively placed at from 5 to 6 feet. The required head should be furnished by the water above the sand, that is, the water level in the first compartment of the regulator well should never fall below the level of the top of the sand. Should this occur, a "negative head" or partial vacuum

will form in the upper portion of the sand bed, resulting in the liberation of some of the dissolved air from the water, thereby causing disturbances in the filtering process. This is especially prone to happen in cold weather, as the dissolved air carried by the water is then at a maximum.

The Theory of Filtration. Filtration is a combination of several processes. The most obvious of these, although not the most important, is the straining out of particles too large to pass the interstices between the sand grains. However, as most of the particles of suspended matter are so small as to readily pass through these spaces, it is obvious that other processes must be acting to remove them from the water. The small pockets formed by adjacent sand grains act as minute sedimentation basins in which the suspended matter may settle. Bacterial action plays a most important rôle. After a filter is in operation for a time a slimy gelatinous film forms on the surface and explorations into the sand will show similar jelly-like matter forming between or coating the sand grains. Examination will show this jelly to be of bacterial origin, as is also shown by the fact that it forms when filtering clear waters. The surface coating has been named the *Schmutzdecke* (dirt cover) by the Germans, who attribute most of the efficacy of the filter to its action, and place so much confidence in it that they consider a sand bed a foot thick sufficient, if properly coated, to yield a satisfactory effluent. The *Schmutzdecke* probably retards much of the suspended and colloidal matter, but the bacterial jelly *within* the sand is also important both because of its straining effect and because it entraps and holds particles of silt and bacteria on the "sticky-fly-paper" principle. The efficiency of a filter increases with age, due to continued bacterial growth and the resulting formation of slime and jelly in the interior. This jelly-like matter is capable of absorbing color from the raw water and may effect a reduction up to 25 per cent. There is also a small amount of chemical action within the filter, in the way of oxidation of the dissolved organic matter contained in the water.

While a properly working filter bars the passage of practically all the bacteria in the raw water, a considerable number may sometimes be found in the effluent. It has been proven by experiment that these result from growths in the sand and underdrains, and also that they are harmless varieties.

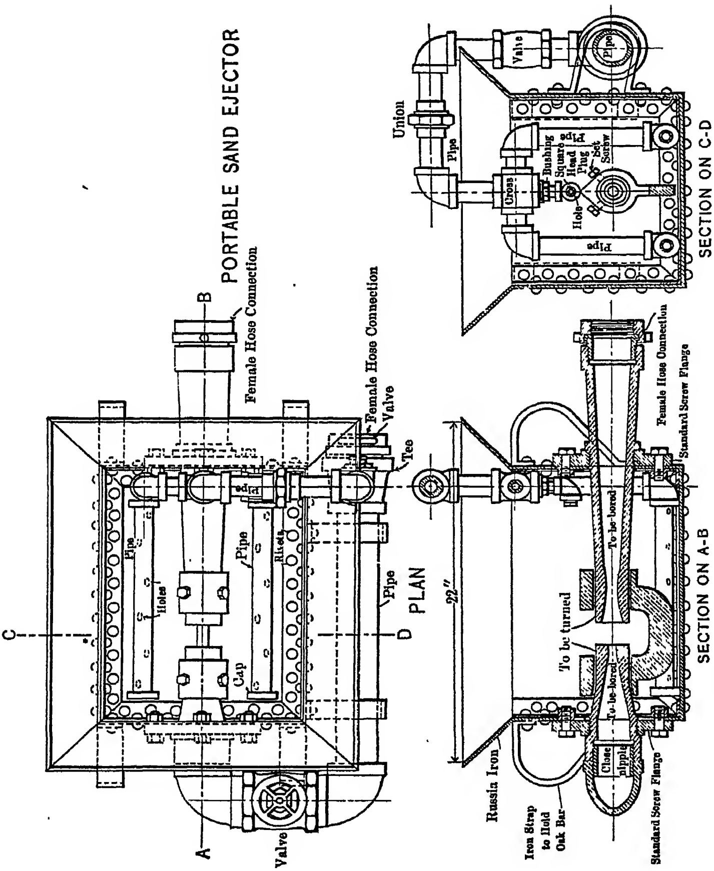

PORTABLE SAND EJECTOR
PLAN
SECTION ON A-B
SECTION ON C-D
Female Hose Connection
Valve
Tee
Pipe
Holes
Cap
Rivets
Union
Cross
Bushing
Hole
Russia Iron
Iron Strap to Hold Oak Bar
Standard Screw Flange
To be turned
To-be-bored
Close nipple
22"
A
B
C
D

Fig. 5.

Raking the Filters. When the loss of head becomes excessive, due to clogging of the filter sand, conditions may be relieved by loosening the surface by means of ordinary rakes. It is found that, after raking, the filter clogs more rapidly than before, so that repeated raking more than twice in succession is impracticable and scraping must be resorted to.

Scraping the Filters. In the lower left corner of Fig. 4 a filter is shown, as it would appear with the roof removed, undergoing the process of cleaning by scraping. The filter is shut down and drained, and the surface of the sand is removed to a depth of one-half to one inch with broad flat shovels, and gathered into convenient piles. The piles of dirty sand are removed by means of a portable sand ejector *t*, shown in detail by Fig. 5.* This consists of a tight metal box containing a large ejector, operating under water pressure furnished by a three or four inch pipe. The sand is shoveled into this box, where it is kept in a fluid condition by water jets from several perforated "irrigating pipes" in the bottom of the box. In this fluid or suspended condition it is drawn into the ejector and discharged through a "sand pipe" (generally 4 inches in diameter) leading to the sand washers *u-u*. Pressure and sand pipes are located, with convenient outlets, along the filter walls, so that the ejector can be attached at any desired point by means of hose connections. The sand washer is shown in detail by Fig. 6.† It consists of a conical metal hopper, in the throat of which are located an ejector and an auxiliary jet, the purpose of which is to supply sufficient water to maintain a continual upward current which escapes by means of the overflow notch at the top of the hopper. The mixture of dirty sand and water from the filter enters the hopper from above and settles toward the bottom against the continual upward current from the auxiliary jet. The dirt and silt are thus removed and carried up and out of the hopper via the overflow. The sand settles to the bottom, where it is seized by the ejector and carried through piping to the sand storage bins *x-x*. Two washers are generally operated in series, washing the sand twice, and the dirty overflow water passes through several concrete boxes *w* on its way to the sewer, so that any fine sand carried over may be trapped therein,

* Trans. Am. Soc. C. E., 1904, l. III, p. 227.

† Trans. Am. Soc. C. E., 1906, l. VII, p. 586.

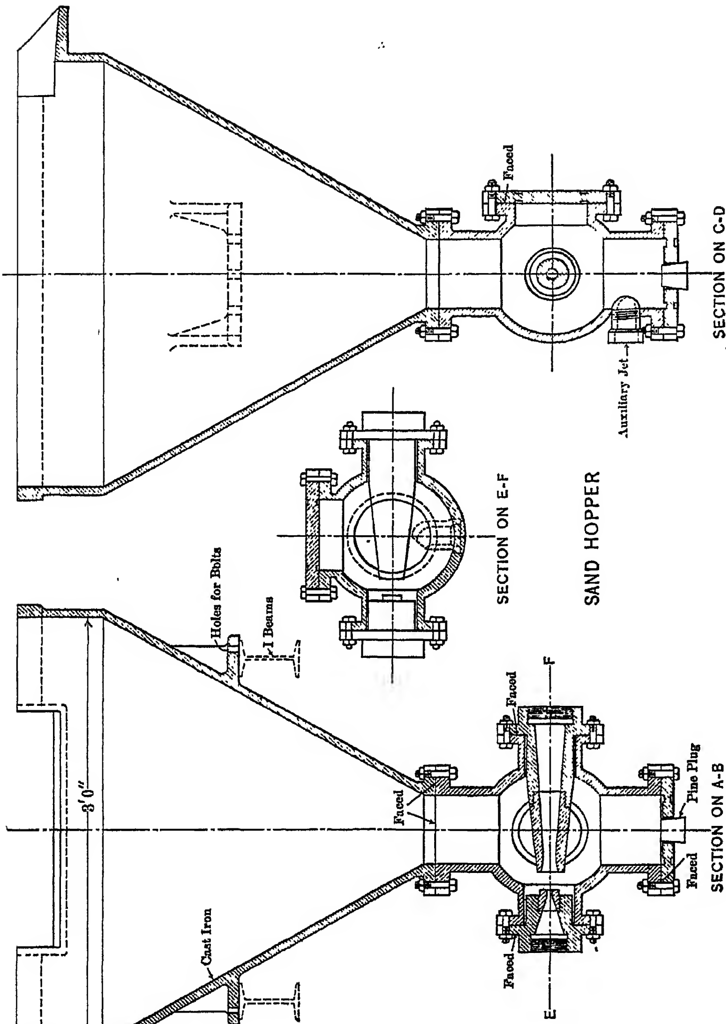


Fig. 6.—Sand-Washing Machine.

preventing the clogging of the sewer. The sand bins *x-x* have conical bottoms provided with drains, so that the water may be removed from the sand.

In winter it is difficult to wash sand, owing to trouble with freezing pipes, ice, etc., and it is therefore customary to scrape the sand into piles, to await the advent of warmer weather for washing. If these piles tend to grow so large as to seriously cut down the effective area of the filter, open-bottomed boxes or frames are placed in the filter and the sand shoveled into these. being thereby more closely confined.

The frequency of scraping is a factor of the turbidity of the settled water and the rate of filtration. In the worst cases it may be required at intervals of a few days; under favorable conditions the period between scrapings may be from four to six weeks. The advantage of preliminary sedimentation in this connection is obvious.

After scraping, the sand surface is smoothed and the filter is slowly filled with purified water from below, and when this has risen well above the sand, raw water is introduced and filtration slowly started, with frequent examinations as to the quality of the effluent.

Replacing Sand. When, by several scrapings, about a foot of sand has been removed, the filter is *resanded* to its original level. To do this, it is first scraped to a greater depth than usual, to make sure of removing all the dirty sand, and is then filled with water to the level at which it is desired the sand surface should come. Ejectors placed in the sand bins discharge clean sand through *sand return* pipes terminating in lines of hose which are floated on small rafts over the surface of the filter to be resanded, and which are guided so as to distribute the sand evenly. When the desired level is reached, the water is drawn down, the surface smoothed over, and the filter started.

General Operation. The general remarks on operation given hereafter apply to slow sand as well as to rapid sand filtration. If coagulants are used, the tests and methods given apply; if not, the chemical tests, in the main, may be omitted, and much stress placed on the bacterial tests. The interpretation of tests as regards bacteria and coli holds also. Much attention should be given to bacterial tests of the effluents of individual filters.

Sterilization. It has become customary of late years to treat

the filtrate with hypochlorite of lime, as an additional precaution. This is explained in detail in Chapter VI. Needless to say, the hypochlorite cannot in this case be applied to the settled water, as this would interfere with the bacterial action within the filter.

Modern Tendencies in Slow Sand Filtration. There is a tendency toward increased rates of filtration, in the most recent plant 6,000,000 gallons per acre per day being used. With turbid waters adequate coagulation and sedimentation have been introduced, as an adjunct to higher rates, and to relieve the filters of part of the load. Extensive experiments have been made with apparatus for washing the sand in place, but as yet have not been entirely successful. Centralization of control by leading all piping to one common regulator house has also been attempted. It will be seen that all these improvements tend toward a quasi-mechanical type of filtration.

Mechanical Filtration. The primary difference between rapid or mechanical and slow sand filtration is in the higher rate used in the former process—100 to 150,000,000 as against 3,000,000 gallons per acre per day, or about 50 to 1. This high rate necessitates relieving the filters of the burden of removing coarse suspended matter, which is accomplished by coagulation and sedimentation. It also follows that, as the rate of clogging the sand varies directly with the rate of filtration, the filter beds must be cleaned daily, and of necessity this must be done *in situ*, to avoid a laborious removal and replacing of the sand. Since there is no time for the formation of a *Schmutzdecke* by natural biological processes, a substitute must be supplied in the shape of a jelly-like film, or "mat," of coagulum, which forms with great rapidity on starting the filter after cleaning.

Description of Plant. Fig. 7 shows a typical rapid sand filtration plant. The general similarity, in parts and arrangement, to the slow sand plant is readily grasped. The most striking feature is the contraction or concentration of the whole plant as compared with the slow sand type. The settling basin is present as before, but is often deeper and of a different type of construction and more thoroughly baffled. The office and laboratory building remains, containing also the coagulant apparatus and storage, for which reason it is frequently called the "coagulant house or building." The *court* between the filters assumes a different shape, though maintaining its functions, by being divided into a lower story or

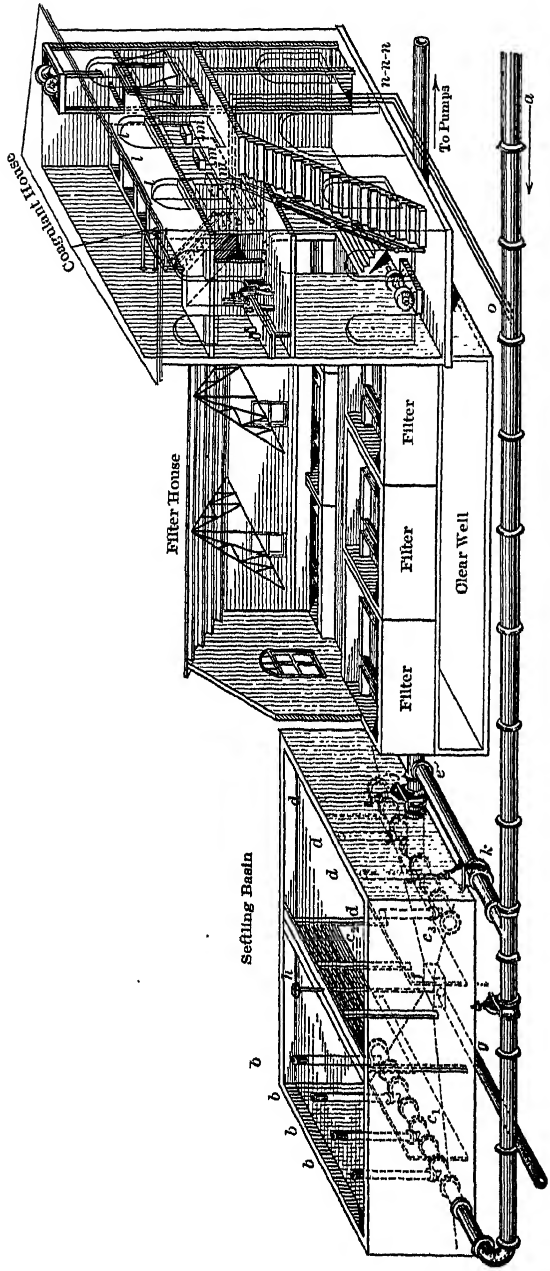


FIG. 7.—General View of a Mechanical Filter Plant.

pipe gallery, containing the piping, valves, and regulating devices, and an upper *operating platform*. We may imagine the individual regulator houses as expanding and merging into one continuous structure over both the former court and the greatly contracted filter units, their former locations being indicated only by the remaining characteristic groups of valve stands on the operating platform.

The advantages of this new arrangement as regards ease of operation and access to all parts are easily seen. The whole filtering area is under the eye of the operator; he may examine the distribution of the raw water and its quality at all points. By manipulating a few valves, he may drain any unit sufficiently to examine the sand surface and mat, in a very short time. The tendency toward vertical stratification of the sand is nullified by the small area, and a uniform horizontal hydraulic grading of the sand bed is maintained by frequent washing. The capacity of the units is generally less than those used in slow sand filtration, so that the effluent may be more closely controlled by individual samples, and any defective unit can be shut down immediately, with small loss of pumped and coagulated water, and the fault can be found and corrected with a minimum of labor. The formation of the mat, or artificial *Schmutzdecke*, can be controlled as to consistency and thickness by applying coagulants directly to the raw water in the filter after washing.

Two important differences in the theory and operation are these: bacterial growths in the filter bed are not required, owing to the artificial mat formation; therefore the beds may be sterilized by adding hypochlorite to the settled water, and the presence of "after-growth" bacteria in the effluent done away with. *Negative head* in the sand bed, so scrupulously avoided in slow sand filtration, is featured in the rapid process, as decreasing the necessary depth of filter tubs and tending toward a uniform distribution of rate over the bed. This is possible because the filters are washed so frequently as to minimize the chance of sufficient air being liberated within the bed to affect the operation.

Settling Basins. The settling basin shown in Fig. 7 is constructed of reinforced concrete, of a type frequently adopted where land is limited or expensive, as the vertical side walls give a maximum capacity with the least area. A basin similar to that shown in Fig. 4 with earth embankments is less frequently used for me-

chanical filter plants. The water enters through the inlet manifold, terminating in the risers *b-b-b-b*, which may extend above the water, acting as aerators as shown, or not, according to the conditions to be met. The basin is provided with baffles, C_1-C_2-C_3, whose function it is to prevent undercurrents and to maintain a uniform flow throughout the basin. After passing through the basin the water is collected by the risers *d-d-d-d* of the outlet manifold and carried to the filters through the settled water main *e*.

The floor of the basin is of smooth concrete with a decided pitch from all sides toward the center, where a sump *f* is located. In this sump is a drain valve operated by a handwheel *h*, by means of which the basin may be emptied for cleaning through the drain *g*. After being emptied, the remaining mud is washed out through the drain by means of a hose. Fig. 7 shows a single basin, which necessitates either shutting down while cleaning, or by-passing the water directly to the filters by closing valves *i* and *j* and opening valve *k*. Many plants have duplicate basins, one of which may be cleaned at a time without interference with the operation of the plant.

Coagulating Apparatus. The coagulant house shown is three stories high. The first floor forms the main entrance to the filter house, contains the wash-water pumps, air compressor, receiving room and storage for coagulants, stairway to upper floors, etc. The second floor contains the combined office and laboratory, the solution tanks *l-l-l* and orifice boxes *m-m-m*, from which pipes *n-n-n* carry the coagulant solution and discharge it into the raw water main *a* at *o*. Sometimes additional coagulant pipes are provided, so that the coagulants may be introduced at the center baffle of the settling basin, C_2, or into the settled water main *e*. The third floor is on a level with the tops of the solution tanks and is used for charging these and for coagulant storage. It also contains a scale for weighing chemicals and the stirring apparatus of the tanks. An elevator or hoist is installed, serving all floors, but primarily for carrying up barrels and sacks of coagulant to the third floor.

Fig. 8 shows in section a typical solution tank and orifice box. Except when used for lime, these tanks are generally built of reinforced concrete. On top of the tank is a dissolving box with a perforated bottom, into which the weighed coagulant is dumped

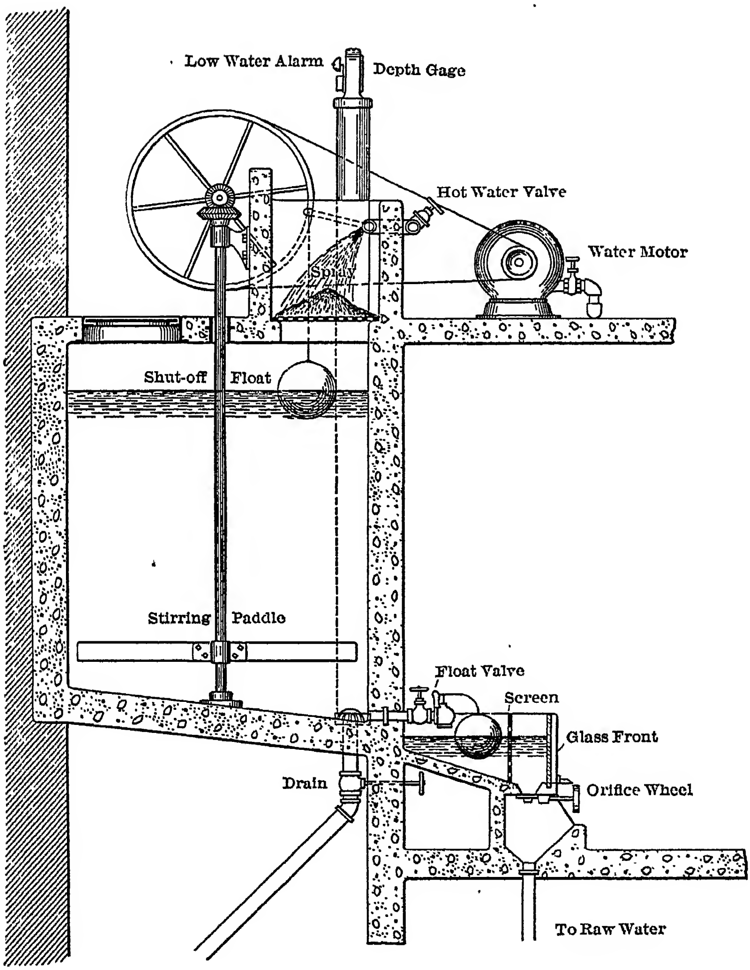


FIG. 8.—Section of a Coagulant Tank and Orifice Box.

and dissolved by a spray of hot water, the solution flowing through the perforations into the tank. An automatic float shuts off the hot water when the tank is full, to prevent overflowing. Before starting to use the solution the operator closes the hot-water valve by hand. In the tank are mixing paddles attached to a vertical shaft, rotated by bevel gearing, belt-driven from a water or electric motor. These paddles keep the solution thoroughly mixed and of uniform strength throughout.

From the bottom of the tank, a short valved pipe connection leads to the *orifice box*. It is the function of this device to feed the solution into the coagulant pipe at a constant rate, regardless of the amount in the solution tank. To this end a float valve on the inlet maintains a constant head on an orifice or opening in a thin metal plate in the bottom of the box, under which conditions, by the laws of hydraulics, the flow through the orifice will be constant and proportional to its area of opening. A sliding or rotating disk allows this area, and consequently the rate, to be varied, and a graduated handwheel is provided, so that the size of opening may be known to the operator. A screen across the box prevents large particles from obstructing the orifice, and the glass front allows the operator a view of the interior, and, by a *mark* etched upon it, tells him at a glance whether the water in the box is at the correct level, a most important point, as the rate of flow varies with the water level over the orifice. This is but one of a very diverse variety of orifice boxes, which differ in detail, but not in principle. Some are arranged to automatically vary the orifice opening with variations in the rate of the raw water, a desirable point if it does not lead to neglect by the operator, for automatic devices act as such only when given the necessary attention, which is increased over that required by simple non-automatic, in proportion to their degree of complexity.

The solution tank should be provided with a float gage for indicating the depth of solution and having in conjunction a *low-water alarm*, consisting of an electric bell which will ring when the solution tank is about to become empty. The dial of the float gage is conveniently graduated as in Fig. 9, where it is seen that, besides the depth scale, concentric scales are added corresponding to the opening of the orifice box, these being graduated in hours, so that in charging the tank, knowing the opening of the orifice box and length of run, the operator can fill the tank to the required

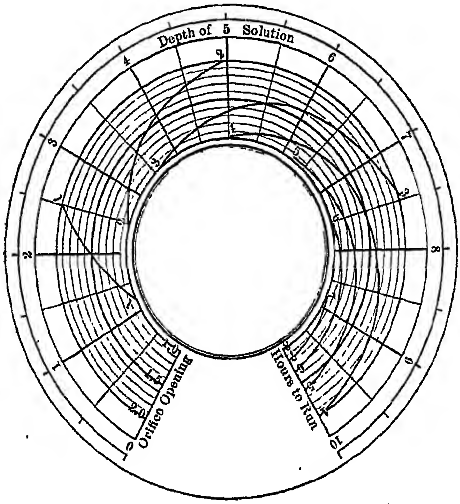


FIG. 9.—Dial for a Solution Tank Depth Gage.

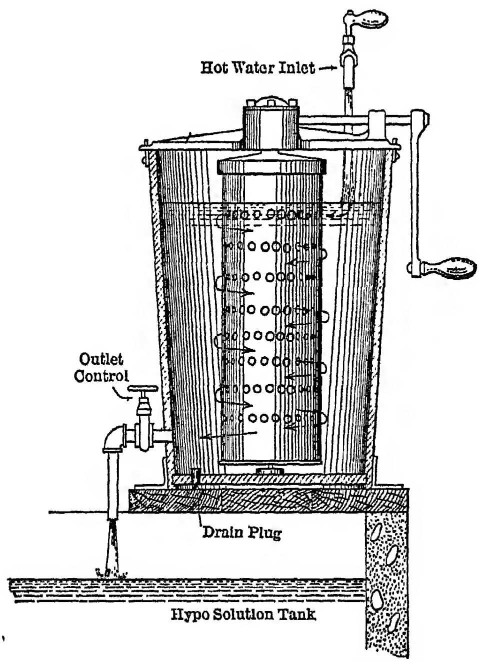


FIG. 10.—Dissolving Device for Hypochlorite of Lime.

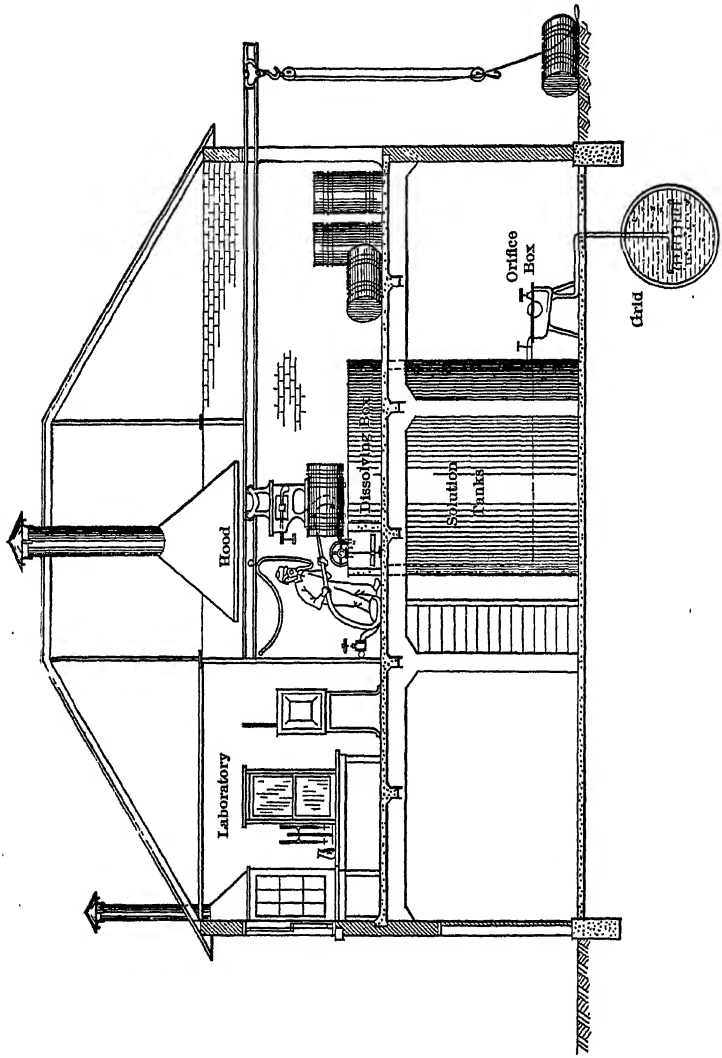


FIG. 11.—Hypochlorite Plant for Sterilizing an Unfiltered Water Supply.

depth, or if the opening of the orifice is changed during a run, he can tell at a glance how long the tank will last at the new rate.

Each solution tank is provided with a drain and valve for cleaning purposes.

Lime cannot be dissolved directly in the manner described, but before being poured into the solution tank must be slaked, as described in Chapter IX. This requires the use of iron slaking boxes.

Hypochlorite of lime presents some difficulties owing to its comparative insolubility and its lightness, causing it to float on the water like flour. The home-made device shown in Fig. 10 is very handy for dissolving hypo in small plants. It consists of an ice-cream freezer, with the can perforated with numerous small holes (say one-eighth inch). The freezer pail is bolted solidly to the top of the solution tank. A valved drain is provided from the freezer to the tank, as well as a supply of warm water to keep the pail filled. The weighed hypo is placed in the perforated can, and the pail filled with water. On turning the freezer the paddles force the hypo toward the periphery of the can by centrifugal force, and the scrapers squeeze it through the perforations in the can. The freezer should be large compared to the amount of hypo used, and all possible parts should be well coated with asphalt paint, to prevent corrosion.

Fig. 11 shows a hypochlorite plant suitable for treating the unfiltered water supply of a city. It consists of dissolving apparatus, two orifice boxes, two solution tanks, stirring devices, hypo storage, and laboratory. To dissolve the hypo, which is received in sheet-metal canisters, a canister is suspended from the traveling scale and run over the dissolving box. The attendant cuts two holes in the end of the canister, one at the top and one at the bottom. By directing a stream of water under pressure into the upper hole, the hypo is washed out through the lower hole into the dissolving box. Thence it flows into one of the solution storage tanks and passes through the orifice box into the water. In dissolving the hypo, the attendant wears a mask and goggles and receives fresh air under slight pressure through a hose. Thus annoyance from fumes and dust are obviated. A similarly designed apparatus can be used in connection with filtration plants.

The Filters. Figs. 12 and 13 show respectively the part plan

and section of a modern concrete filter house. Referring to Fig. 13, it will be seen that the filters are in two rows, with the pipe gallery and operating platform between them, and a subbasement for filtered water storage below, making a very compact and economical arrangement. The water from the settling basin enters the pipe gallery through the settled water main *e*, extending the length of the gallery with a valved branch to each filter. The level of the water on the filters may be regulated by float valves attached to the ends of the settled water inlets, as shown in the right-hand filter of Fig. 13, or the level for all the filters may be fixed by an overflow pipe in the settling basins.

The nature of the filtering material through which the water passes is shown in the section, Fig. 13. It consists of a 30-inch layer of sand similar to that used in slow sand filters in quality, but slightly coarser (effective size 0.4 to 0.6 mm.). In operation it is covered with a mat or film of coagulum. The sand rests on about a foot of graded gravel, generally increasing in size from one-eighth inch at the top to three-quarters inch at the bottom. The gravel in turn is supported by perforated brass strainers, through which the water passes to the collector pipes below. Fig. 14 shows several types of strainer systems. The upper type is extensively used in plants using a high rate of wash. The bottom of the filter is molded into a series of parallel ridges and grooves, approximately of the dimensions shown, all leading to a central collecting gutter. The grooves or valleys have ledges on which rest perforated brass plates supporting the gravel. The portion of the groove below the strainer plate serves as a collecting channel for the filtered water. The gravel is confined between the ridges and is held down against the upward pressure while washing by a brass wire screen. A somewhat similar strainer system is in use at the Columbus, Ohio, plant and is shown by Fig. 42. The lower types are in general use at plants where both air and water are used in washing, and are similar to that shown in Fig. 13. There is a main collector through the center of the filter with lateral pipes (generally 2-inch diameter and spaced six inches on centers). Into these lateral pipes brass strainers are screwed. The left-hand side of the cut shows the arrangement for separate air and wash-water manifolds. In this case the perforated brass air laterals are placed just above the gravel. The strainer heads shown are of the slotted type, the wash water being distributed laterally through

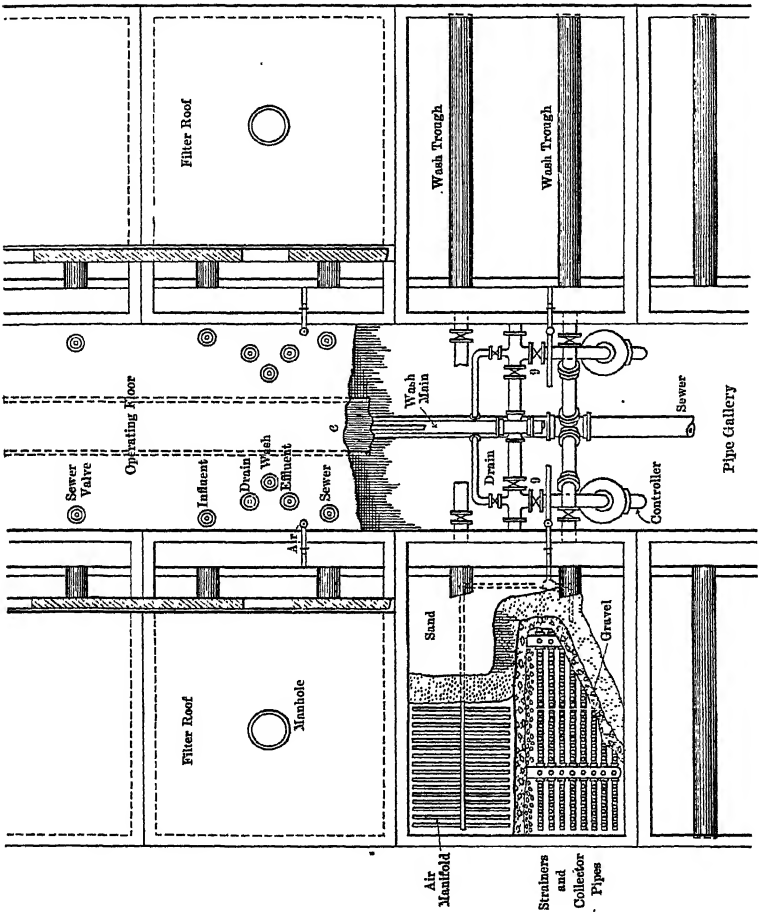


FIG. 12—Plan of a Small Filter Building, Showing Filter Units and Piping.

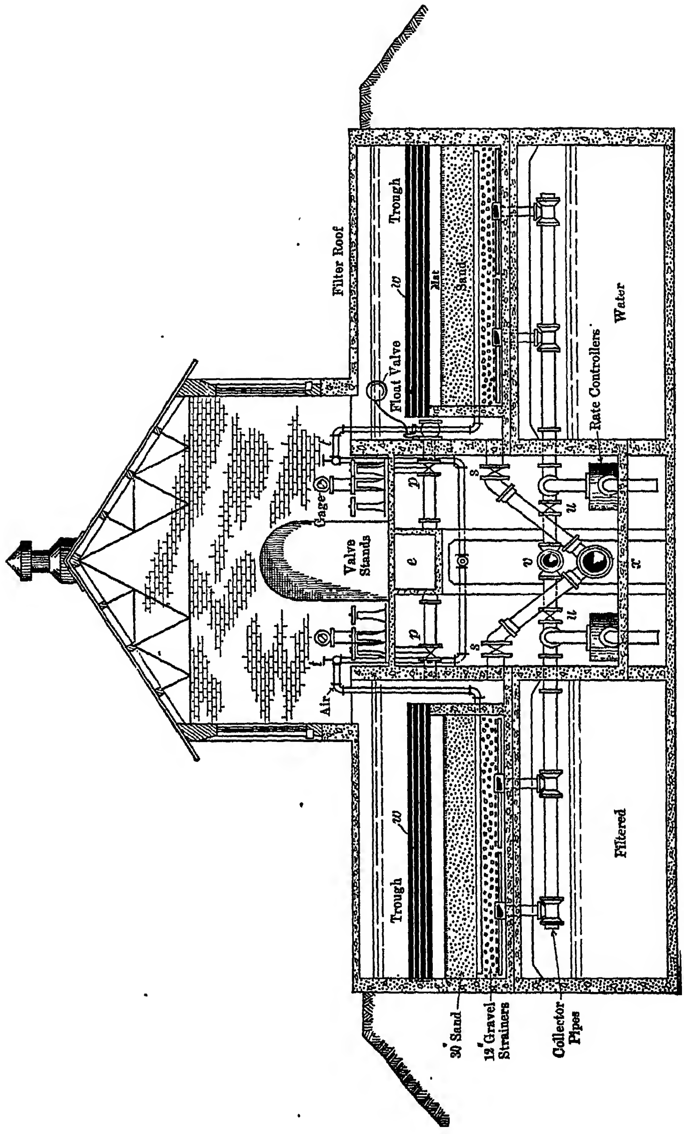


FIG. 13.—Sections Through Filters and Pipe Gallery of a Mechanical Filter Plant.

the slots. The right-hand strainers are of the patented combined air and wash-water type (Williamson strainers). It will be noted that the strainer shanks extend almost to the bottom of the lateral pipes. To wash with air, the air is admitted to the upper half of the lateral pipes, which contain sufficient water to seal the

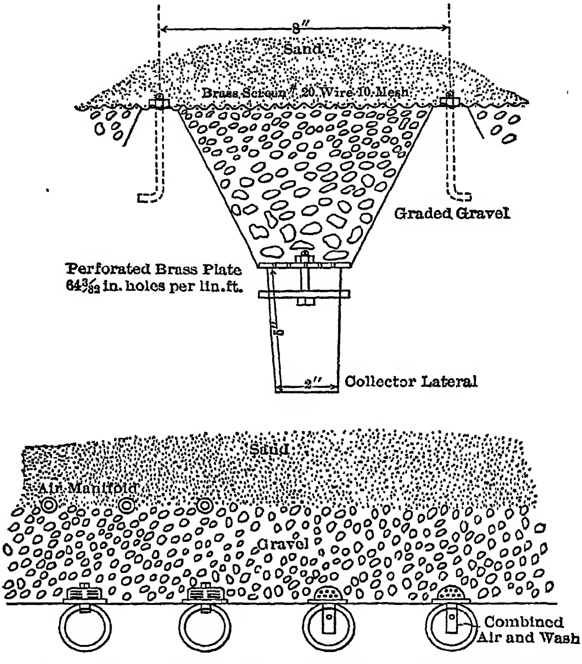


FIG. 14.—Typical Strainer Systems Used in Mechanical Filters.

extended ends of the strainer shanks. The air escapes through the strainers via small holes drilled in the shanks of the strainers. There are many types of strainers in use other than those described.

As in the case of slow sand filters, the laterals discharge into a main collector, bisecting the filter, which carries the filtered water to an effluent or rate controller, situated in the pipe gallery, one being provided for each filter unit. Owing to the rapid increase in loss of head, automatic control is here imperative. If the filters

operate under negative head, the controllers are set some distance below the filters, which requires them to regulate equally well with their outlets under back pressure from the clear-water basin.

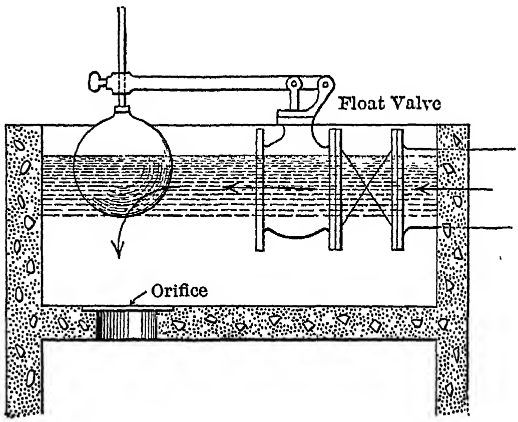


FIG. 15.—Rate of Flow Controller for Mechanical Filters. Orifice Box Type.

It is also desirable that they should operate with a minimum difference of head. The conditions practically eliminate the fixed-

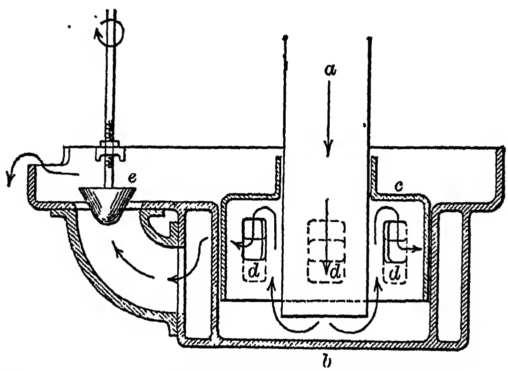


FIG. 16.—Rate of Flow Controller for Mechanical Filters. Velocity Type.

head-over-orifice type, Fig. 15 (such as described for the slow sand plant, or an enlarged orifice box), and require a device wherein the velocity head or an artificially created difference of head in the

effluent pipe regulates the area of a valve pro rata. A typical controller of the velocity type is shown diagrammatically in Fig. 16.*

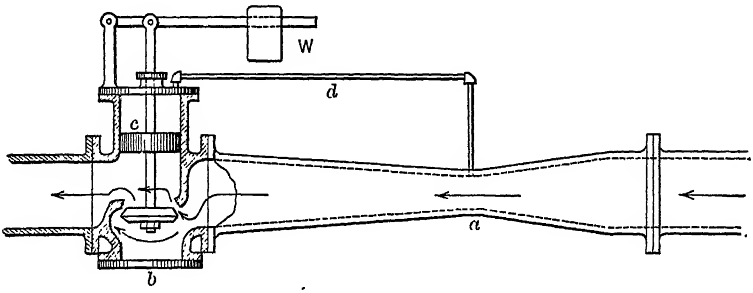
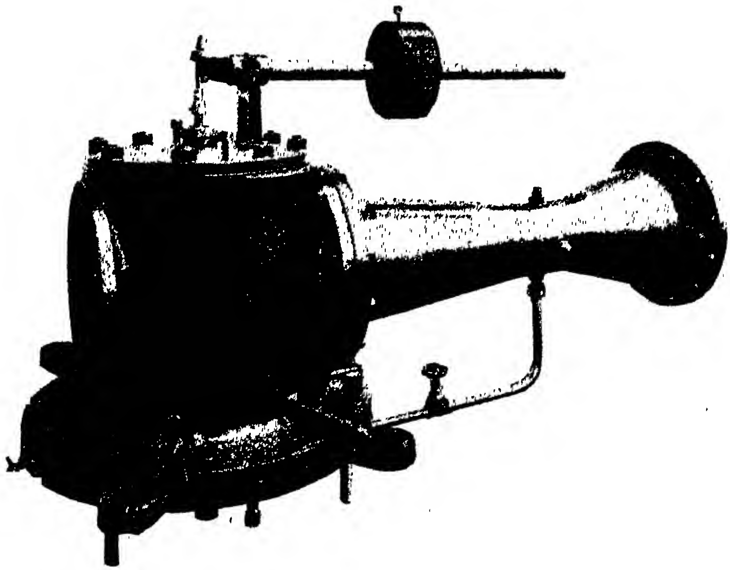


FIG. 17.—Rate of Flow Controller for Mechanical Filters. Venturi Type.



Courtesy Simplex Valve and Meter Company.

FIG. 17a.—Venturi Type Rate Controller.

The water flows downward through the draft tube *a* and striking the plate *b* has its direction reversed so that it impinges on the inverted hollow cylinder *c*, the sides of which form the gates over

* Made by the Norwood Engineering Co. for the Charleroi, Pa., plant.

the apertures *d-d-d*. The impact of the water raises the cylinder in proportion to the velocity in the draft tube, thereby throttling the apertures *d-d-d*, and allowing the water to escape as indicated by arrows. By means of a cone valve *e* regulated from a valve stand on the operating floor, the controller can be set to any desired rate. Fig. 17 is a schematic sketch of a controller of the difference-in-head type. An obstruction, such as a Venturi tube, orifice plate, etc., is placed in the effluent pipe at *a*, followed by a valve *b* whose opening is regulated by the position of the piston *c*. The position of this piston is determined by the difference between the direct upward pressure from below the obstruction and the downward pressure transmitted to the top of the piston from above the obstruction by means of the pipe *d*. The controller can be set to deliver at any desired rate by the position of the weight *w* on the lever arm.

Clear-Water Basin. The clear-water basin, into which the effluent discharges from the controllers, is simply a reinforced concrete tank beneath the filters, for equalizing the load on the high-pressure pumps and furnishing a reserve for washing filters, etc. It is provided with a sump and valve for drainage and cleaning.

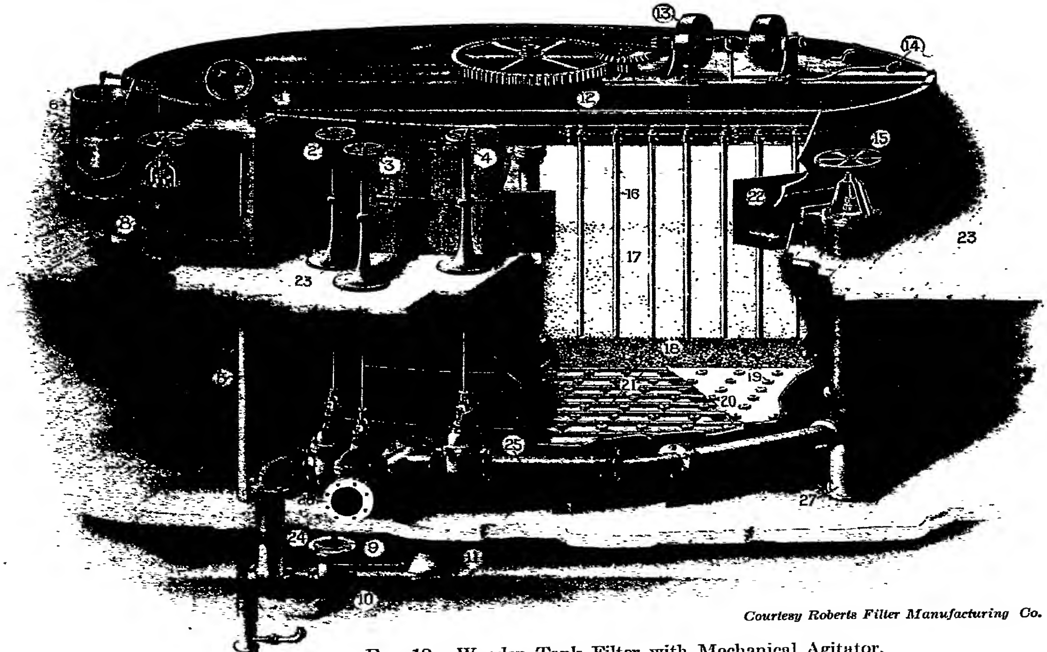
Washing Filters. In washing a filter it is first shut down by closing the settled-water and effluent valves *p* and *q* and draining it to the top of troughs by opening the sewer valve *s*, Fig. 13. Assuming the filter to be piped for air, the compressor is then started and the air valve *t* opened, admitting compressed air to a grid placed just below the surface of the filter gravel which distributes the air uniformly through the sand bed by means of minute perforations in the pipes of the grid. The purpose of the air is to loosen the sand, mix it, and remove dirt by the abrasion of the sand particles. After three to five minutes of air washing the air valve is closed and the wash valve *u*, Fig. 13, is slowly opened. Filtered water flows from the wash-water pipe *v* through the collector system and upward through the strainer openings, which are proportioned to give a uniform upward flow over the area of the filter. The wash water flowing upward through the sand thoroughly cleanses it and grades it hydraulically, the dirty water escaping by means of the wash troughs *w-w*, Figs. 12 and 13, and sewer outlet to the sewer *x*, Fig. 13. After the sand is clean the filter is again put into operation. Washing requires about 12 to 15 minutes per filter.

In some plants the air is omitted, in which case a higher wash velocity is used, and it becomes necessary to tie down the gravel with brass screen or it will be impelled upward into the sand by the wash water. In old plants where the filter units consist of circular wood or steel tanks, mechanical rakes are used for agitation during washing. Such a unit is shown in Fig. 18. A central shaft carries two radial arms with vertical raking bars reaching nearly through the sand and revolved during washing by suitable gearing, generally belt-driven. The other details are readily understood from the figure and correspond to those already described.

Wash water may be obtained by tapping the wash-water pipe into a pressure main, obtaining the required pressure by means of a reducing valve. This involves a waste of pressure and there is also danger from water hammer in the high-pressure mains due to chattering of the reducing valve. A better way is to have duplicate centrifugal wash pumps drawing from the clear-water basin and discharging into the wash-water main at the proper pressure, or, better yet, to have the pumps discharge into an elevated tank of proper height and dimensions to insure a uniform pressure.

Valves, Gages, etc. The valves required per filter are the *Influent* (settled water), *Effluent*, *Wash Water*, *Sewer*, *Air*, and *Filter Drain;* the last being used to completely empty the filter or when it is desired to waste the effluent. These are arranged with valve stands on the operating floor, so as to form a convenient group in front of each filter. In the case of large filters, hydraulically operated valves are used, and the handles for these are grouped together on a table in front of each filter. The controller also has an adjustment by which its rate can be changed from the operating floor. Here, too, are placed the loss-of-head gages, one for each filter, which indicate the friction through the filter, as already explained for slow sand filters, and often gages showing the rate of flow. Each unit should be equipped with an effluent sampling pump, by means of which samples may be obtained at any time for analysis. There should be gages to show the wash and air pressures and floats to indicate the levels of water in the settling and clear-water basins.

Laboratory. The requirements of the laboratory are quite simple. The necessary apparatus is given in the chapters on Bacterial and Chemical Tests. As to the room, it should be dry, well lighted and ventilated, and provided with heat and artificial



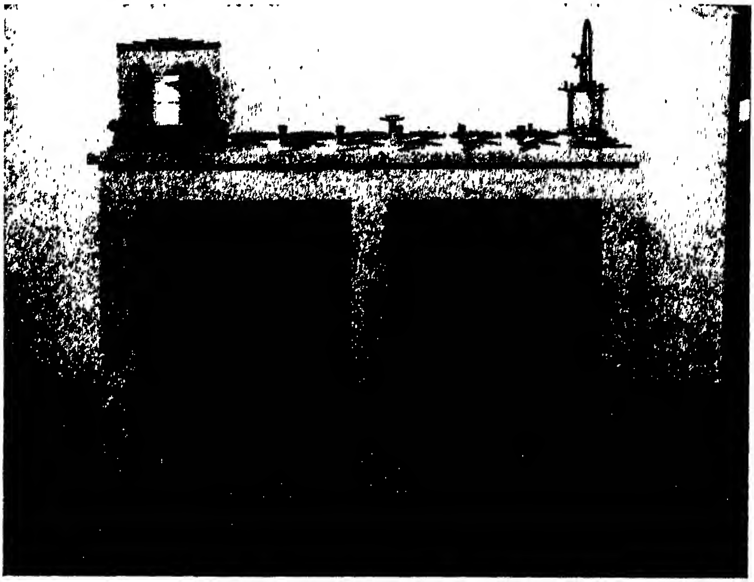
Courtesy Roberts Filter Manufacturing Co.

FIG. 18.—Wooden Tank Filter with Mechanical Agitator.

LIST OF PARTS IN WOODEN TANK FILTER (FIG. 18):

1.—Loss-of-Head Gage.
2.—Filtered Water Effluent Valve.
3.—Wash Water Supply Valve.
4.—First Filtered Water Valve.
5.—Float Tube.
6.—Float Tank.
7.—Float.
8.—Unfiltered Water Influent (Automatic Control).
9.—Orifice Filter Control.
10.—Butterfly Valve.
11.—Float.
12.—Agitator Gears.
13.—Clutch Pulleys.
14.—Shifting Lever.
15.—Waste Wash Water Valve.
16.—Agitator Rake Bars.
17.—Filtering Sand.
18.—Filtering Gravel.
19.—Strainers.
20.—Concrete Fill.
21.—Filtered Water Collecting System.
22.—Supply and Wash Trough.
23.—Operating Platform.
24.—Filtered Water Effluent Pipe.
25.—First Filtered Water Pipe to Drain.
26.—Wash Water Supply.
27.—Waste Water Pipe to Drain.

light, preferably steam and electricity. It should be provided with gas for use in Bunsen burners, autoclave, sterilizers, etc. The incubators are preferably heated with electricity, as being least troublesome. The principal work table should be located in front of a large window, preferably facing north, and should



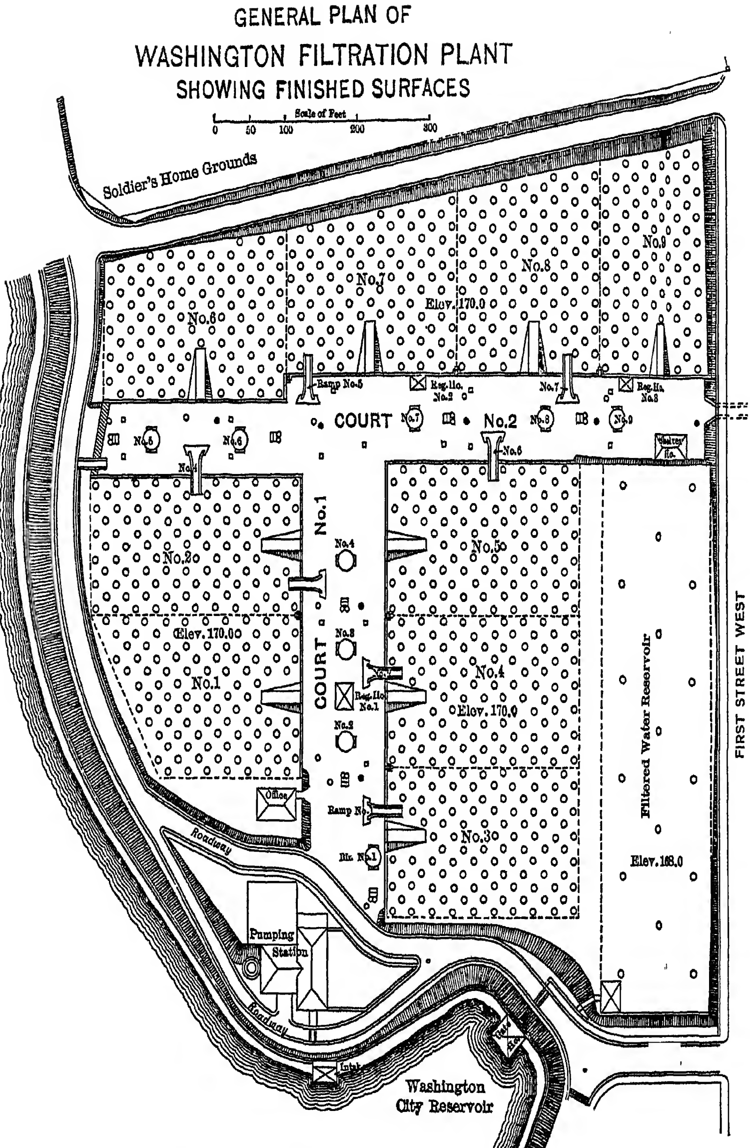
Courtesy Pittsburgh Filter Manufacturing Co.

FIG. 18a.—Typical Operating Table Showing Levers for Operating Hydraulic Valves, Recording Loss-of-Head Gage (on Left), and Effluent Sample Pump (on Right).

have a slate top, or one of heavy wood, painted a dull black. The reagents should be handily placed on shelves above the table, and drawers should be provided for filters, test tubes, etc. There should be a sink provided with hot and cold water, an ice-box, and a water still.

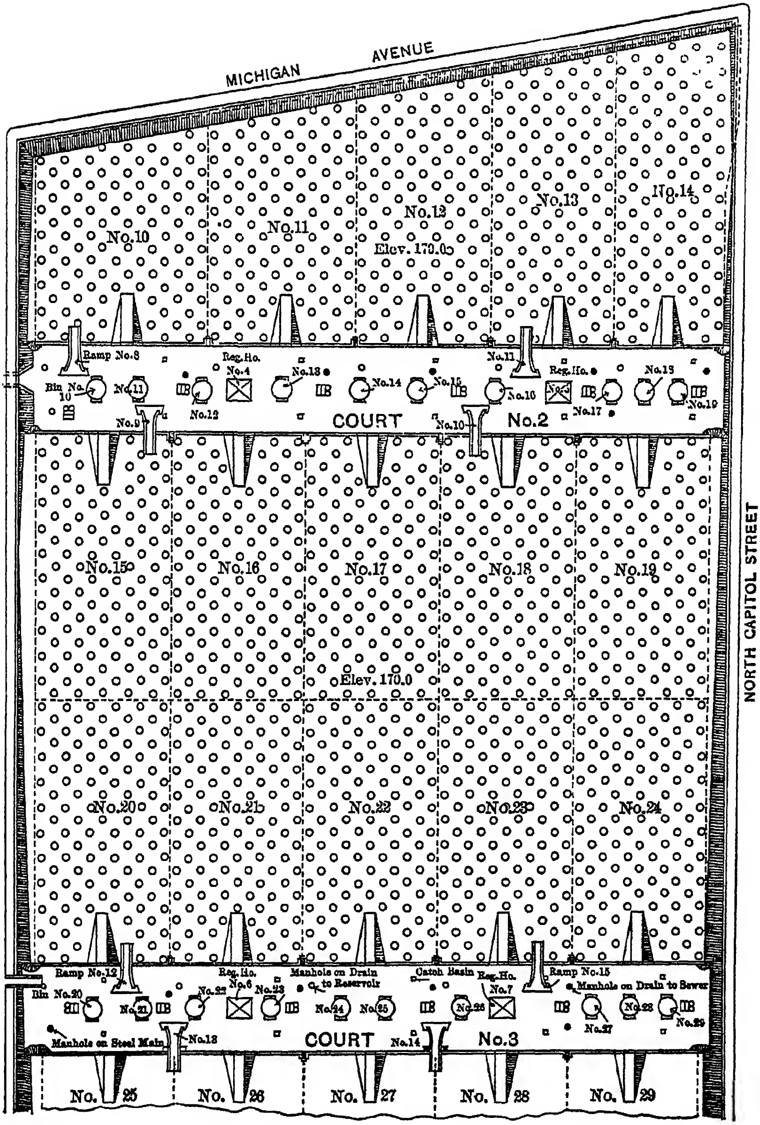
Much can be done by a small expenditure for extra apparatus to expedite the tests. Thus by using self-filling burettes and a complete set of apparatus for each test, kept ready for use and set up in definite places in the order in which the tests are made, much needless walking about to get apparatus is done away with.

There should be a desk and chair for the chemist and a filing



From Trans. American Society of Civil Engineers, Vol. LVII.

FIG. 19.—General Plan of Washington



Filtration Plant Showing Finished Surfaces.

system for the records, but superfluous chairs and furniture are to be avoided as tending to make the laboratory too comfortable a place for visitors.

Mechanical Filtration and Water Softening. The mechanical filter plant is adapted, with a few slight alterations, to do efficient work in water softening. The principal requirements to fit it for this work are an ample settling basin and larger facilities for storing and handling coagulants, especially lime. This matter is more fully taken up in Chapter VII, on Water Softening.

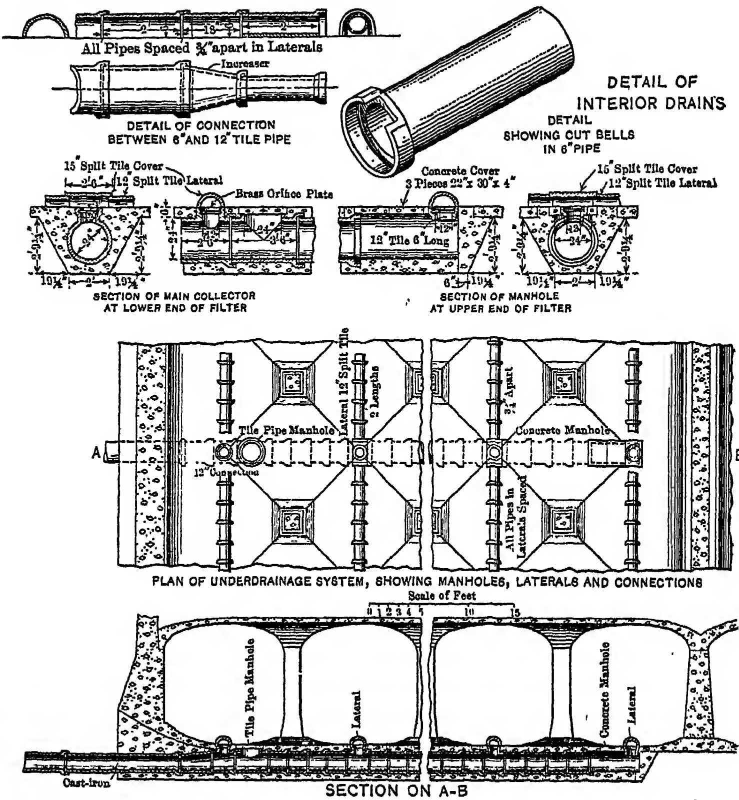
Mechanical Filtration and Iron Removal. The removal of iron in conjunction with mechanical filtration is accomplished by aeration followed by treatment with lime and some aluminum sulphate, as the precipitate formed by lime alone is too fine to be readily filtered out. This is treated fully in Chapter VI, Coagulation and Sterilization.

The Slow Sand Filtration Plant at Washington, D. C.* The water supply of the City of Washington is obtained from the Potomac River by a diversion dam above the Great Falls, being conducted thence to the city through an aqueduct and tunnel of an aggregate length of 90,000 feet. Two large reservoirs, each of 150,000,000 gallons nominal capacity, are located along the aqueduct, and this terminates in a third reservoir of 300,000,000 gallons capacity situated within the city proper, at a sufficient elevation to supply most parts thereof by gravity, a few exceptionally high points being supplied by means of booster pumps. The capacities given are nominal, about 300,000,000 gallons being actually available from the three reservoirs. The aqueduct has a capacity of 75,000,000 gallons per day.

As considerable sedimentation is secured in the reservoirs, no additional basins were built, the water being pumped directly from the last (Washington City) reservoir to the filters which are adjacent thereto. The pumping equipment consists of three engine-driven centrifugal pumps, each of 40,000,000 gallons per day capacity, located in a pumping station built as part of the filtration project. The lift from the reservoir to the water level on the filters varies from 21 to 35 feet as the reservoir is drawn down.

* "Works for the Purification of the Water Supply of Washington, D. C." By Allen Hazen and E. D. Hardy, Trans. American Society of Civil Engineers, Vol. LVII, p. 307.

As the close regulation of centrifugal pumps under varying head is difficult, allowance was made for a fluctuation of 6 inches in depth of water on the filters, which gives an aggregate margin of 4,000,000 gallons. The filtered water is collected in a pure-water reservoir,



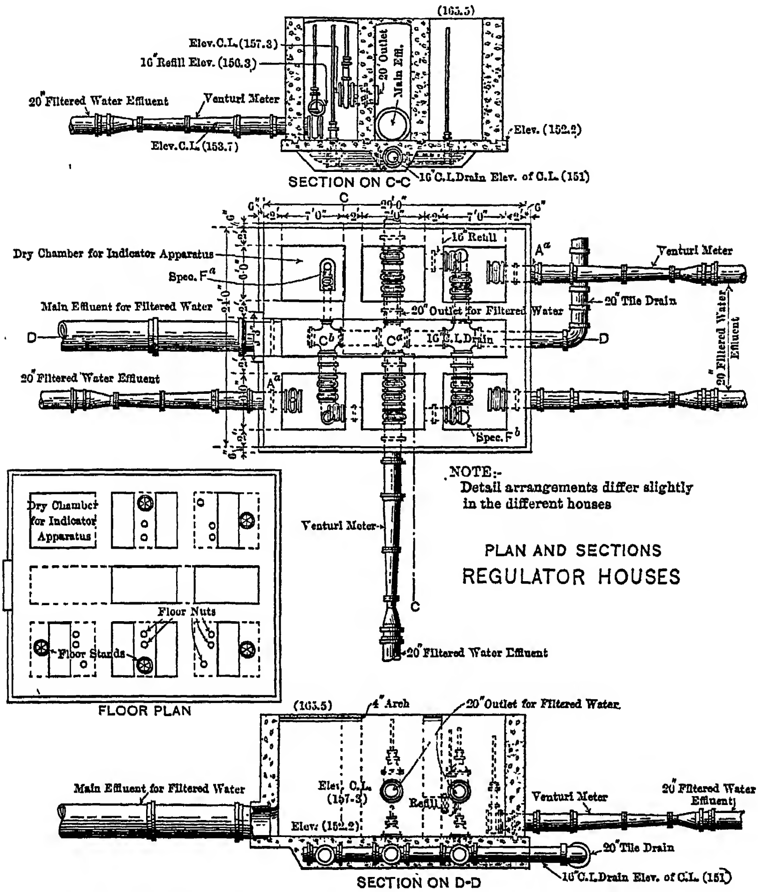
From Trans. American Society of Civil Engineers, Vol. LVII.

FIG. 20.—Details of Filters, Washington, D. C.

roofed with a concrete groined-arch construction, of 14,000,000 gallons capacity, whence it is supplied to the city through a set of equalizing float valves.

The arrangement of the plant is shown by Fig. 19. It is irregular, as the available ground was limited and had to be used most economically. There are twenty-nine filters, each having one acre of sand area, so that at the customary rate (3,000,000 gallons

per acre per day) the plant has a daily capacity of 87,000,000 gallons. Allowance must be made, however, for filters out of use due to sand scraping and repairs. It will be noted that the filters

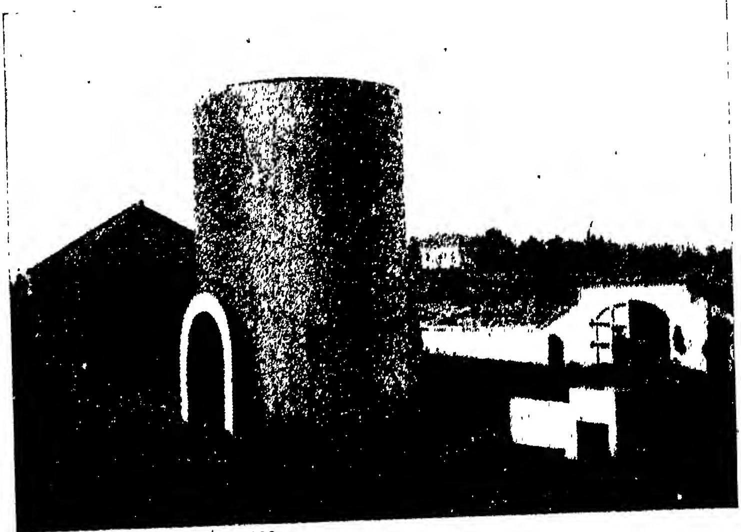


From Trans. American Society of Civil Engineers, Vol. LVII.

FIG. 21.

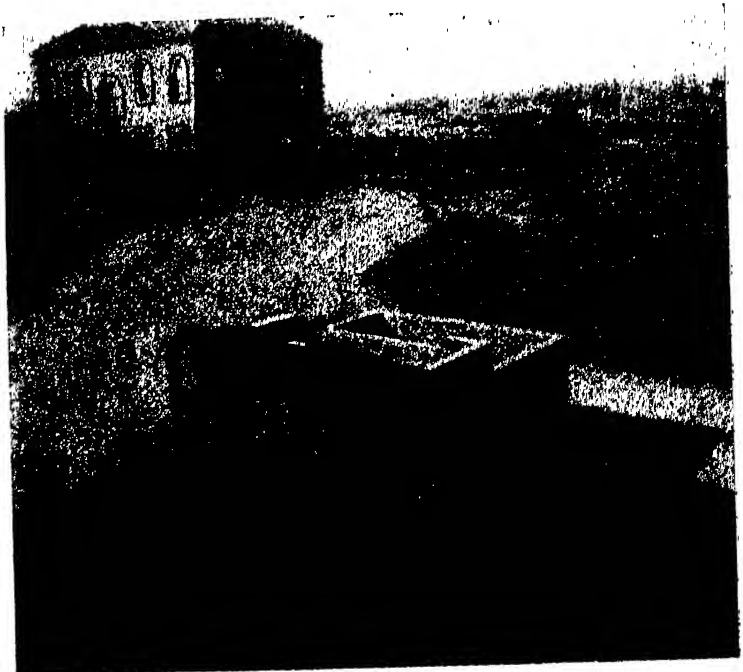
are grouped on each side of "courts" which contain the piping, sand-washing apparatus, etc.

The filters are essentially of the type already described, the principal features being shown by Fig. 20. The walls, floor, and groined-arch roof construction are of concrete masonry, the type of



Engineering Record, April 7, 1906.

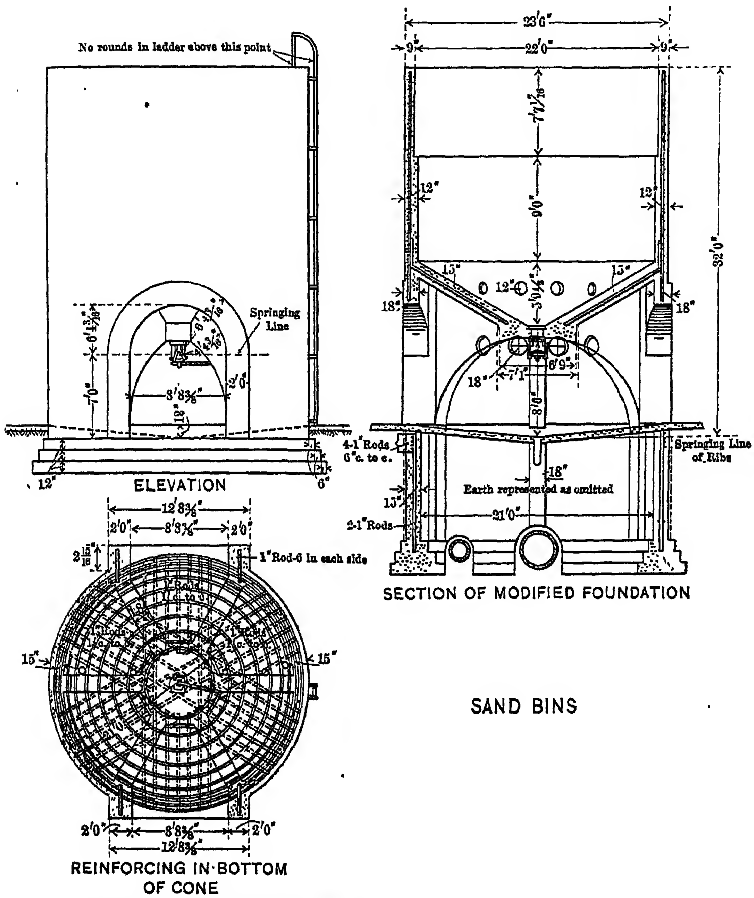
FIG. 22.—Sand Storage Bins, Washington, D. C., Filtration Plant.



Engineering Record, April 7, 1906.

FIG. 23.—Sand Washers, Washington Filtration Plant.

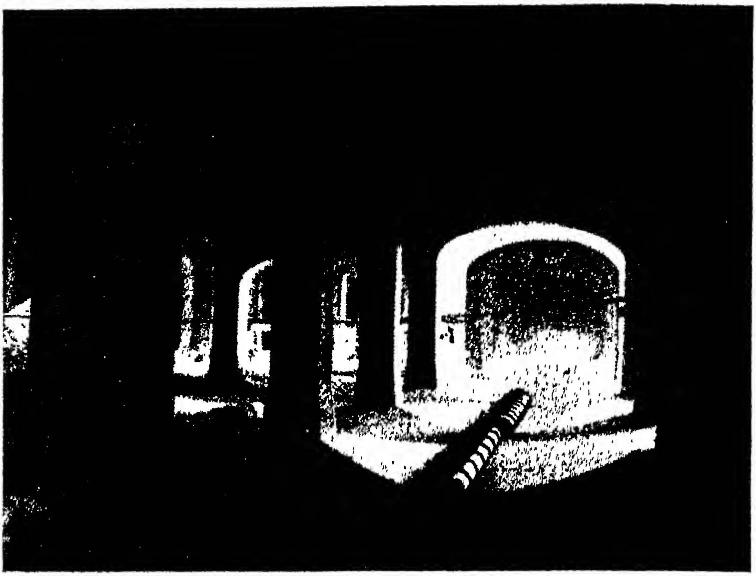
structure being such as to require little reinforcement. The roof is covered with earth and sodded. The central collecting pipe is located below the floor level, and the filtered water is led to it by



Trans. American Society of Civil Engineers, Vol. LVII.

FIG. 24.—Details of Sand Bins, Washington Filtration Plant.

lateral drains of 12-inch half-tile and 6-inch tile, the latter being used near the extremities of the laterals. A peculiarity of construction consists in the interposition of a brass orifice plate at the junction of laterals and main collector for the purpose of compensating for variations in loss of head between those laterals



Trans. American Society of Civil Engineers, Vol. LVII.

FIG. 25.—Interior View of Filter, Washington Filtration Plant (Showing Filter Sand and Gravel Removed). Note Lateral Drains.

Trans. American Society of Civil Engineers, Vol. LVII.

FIG. 26.—General View of Washington, D. C., Filtration Plant.

remote from and those adjacent to the filter outlet. The drainage system is covered with 12 inches of graded gravel supporting 40 inches of filter sand (effective size, 0.32 mm.; uniformity coefficient, 1.77). The working head of water on the filters is 4 feet.

The effluent pipes from the filter units are carried to centrally located regulator houses, of which there are seven, generally arranged to serve five filters each. Fig. 21 gives the details of one such house. The substructure contains six water-tight concrete compartments, five serving as receiving basins for the effluent of the filters, the sixth containing recording mechanism. The filter effluents enter the respective compartments through Venturi meters and valves with graduated handwheels. The Venturi meters indicate and record the rates of filtration for each filter, and adjustments of rate are made by means of the graduated valves. The effluents discharge into a central collecting flume through valved apertures and are carried to the filtered-water reservoir via a main effluent pipe. Facilities for draining any compartment are provided. The superstructure is of brick with stone trimming and tile roof.

The method of handling and washing sand is that already described, and the reader is referred to Figs. 5 and 6 for details of the portable sand ejectors and sand washers used. Fig. 22 illustrates one of the sand storage bins, of which there are twenty-nine. In the left background is the superstructure of one of the regulator houses, and to the right is the entrance to one of the "ramps" or inclined walkways leading into the filters. Fig. 24 shows the details of a sand bin. It is built so that a wagon can drive underneath, be filled with clean sand, which is then delivered into the filters through manholes in the roof.

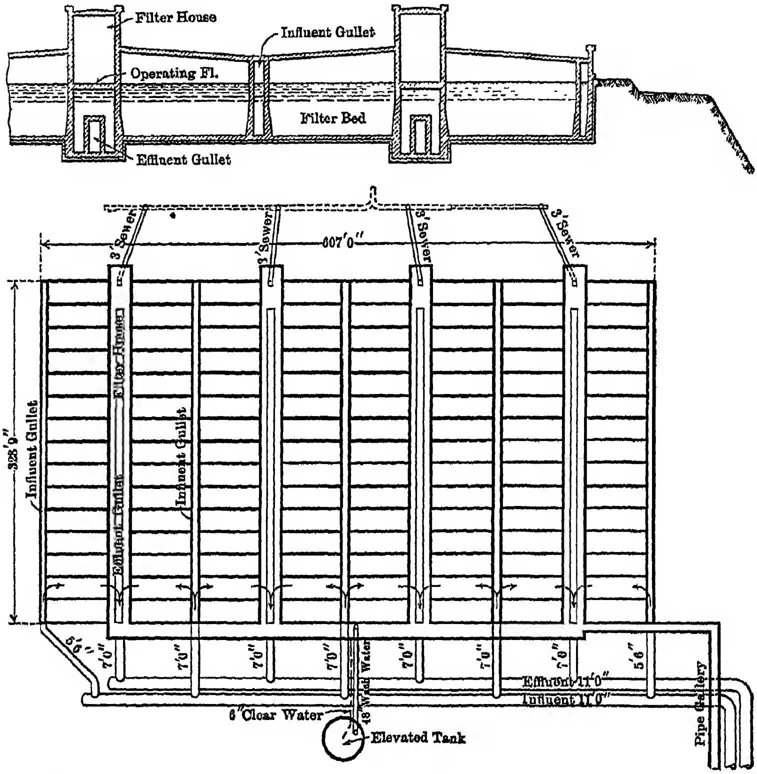
An administration building contains general offices, chemical and bacterial laboratories, lockers, toilets, storerooms, etc.

While no provision was made for coagulation, because of popular prejudice against the use of chemicals, the advantages to be gained therefrom were fully appreciated by the designing engineers and recent experimental work at the plant has more than fulfilled anticipations as to the value of coagulation. Improvements in sand washing have also been made, notably in substituting the ejector method for the use of carts in replacing sand in the filters.

The plant was built under the direction of Colonel A. M.

Miller, assisted by Capt. W. P. Wooten and R. D. Chase. Mr. Allen Hazen was consulting engineer and Mr. E. D. Hardy has had charge of the plant since its completion.

The Torresdale Preliminary Filters at Philadelphia, Penn.* The City of Philadelphia has installed a number of rapid sand-filter plants, with the object of removing the coarse suspended



Engineering Record, November 14, 1908.

FIG. 27.—Torresdale Filtration Plant. Plan and Part Section.

matter from the water preliminary to final filtration. Of these the installation at Torresdale is typical. The original plant was of the slow sand type, similar to that at Washington, already described, and, filtering at a rate of 3,000,000 gallons per acre per day,

* *Engineering Record,* November 14, 1908.

had a daily capacity of 120,000,000 gallons. While the quality of effluent was satisfactory, it was desired to increase the capacity of the filters. By means of the preliminary filter plant here described, it became possible to double the rate of filtration of the slow sand filters, enabling an output of 240,000,000 gallons per day to be obtained.

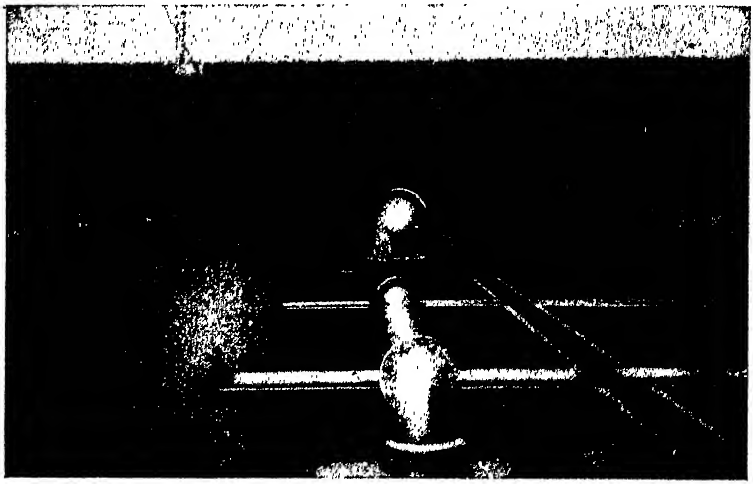
The preliminary filters are adjacent the original slow sand plant, are of 240,000,000 gallons capacity, and essentially of the mechanical type, although somewhat simplified and operated without coagulation. As shown by Fig. 27, the plant consists of 120 beds, arranged in 8 rows of 15 beds each. Each bed measures 20 feet 3 inches by 60 feet, has a capacity of 2,000,000 gallons per day when operated at the rate of 80,000,000 gallons per acre per day, and has a complete system of control valves and piping, manipulated by levers on an individual operating table. There are four filter houses, one between each double row of filters. The raw water is admitted to the filters by means of channels or gullets between the rows of filters, entering at the center of the rear wall, and after filtration is collected in effluent gullets under the filter houses.

The filters, flumes, floors, roofs, etc., are of concrete, reinforced or supported by structural shapes. The superstructure is of face brick trimmed with gray granite.

The raw water is pumped to the preliminary filters from the river through an 11-foot riveted steel conduit encased in concrete. This conduit runs the full length of the filter plant and has three 7-foot and two 5½-foot steel branch connections, leading to the five influent gullets already mentioned. These influent gullets extend the full width of the plant, between adjacent rows of filters, being formed by the back walls of the filter units, except the two outside gullets, where an additional wall had to be added. The raw water enters the filter beds by means of cast-iron pipes in the rear wall, each controlled by a 16-inch hydraulic valve located in the central wash gutter. This is formed in the customary way by two reinforced concrete walls extending longitudinally through the center of the filter and 12 inches apart, dividing the filter bed proper into two equal portions. Steel wash-water troughs extend laterally across the filters at right angles to and level with the tops of the central gutter walls, and serve to convey the wash water to the central gutter, whence it finds its

way to the sewer through a hydraulically operated sluice gate at the front end of the filter. There are twelve such wash-water troughs per filter, being spaced equally, six on each side of the central gutter. The general arrangement of central gutter troughs, etc., is shown in Fig. 28.

The filtering material consists of gravel and sand of graded sizes, decreasing in size upward, viz., at the bottom, 15 inches of gravel, varying in size from 2 to 3 inches; 4 inches of gravel from



Engineering Record, November 14, 1908.

FIG. 28.—Torresdale Filtration Plant. View of Filter Bed.

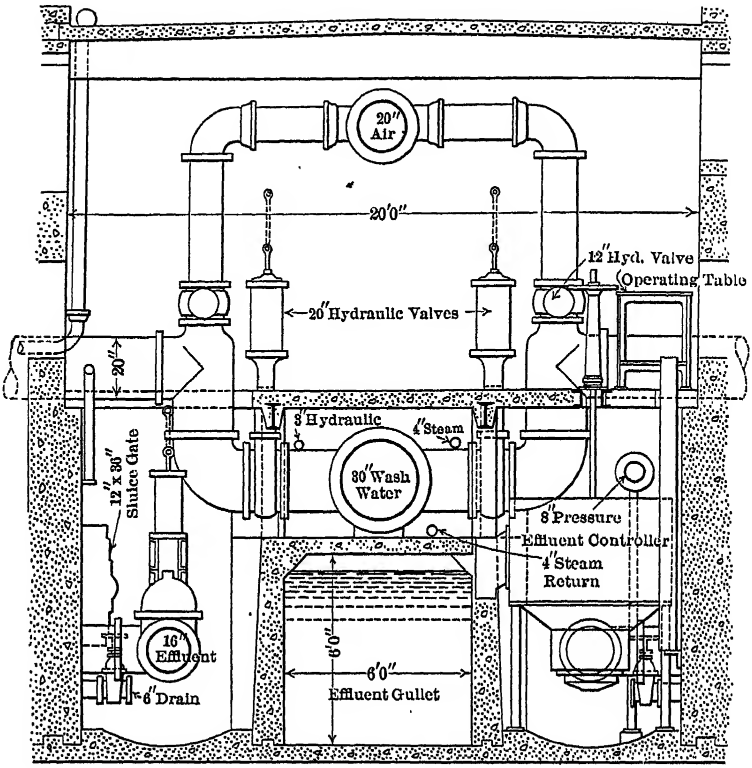
⅝ to 1½ inches; 3 inches of gravel from ¼ to ½ inch; 8 inches from ¼ to ⅛ inch, and a top coating of 12 inches of sand from 0.8 to 1 mm. size. Under the gravel, and running longitudinally through the center of each of the two equal filter beds into which the unit is divided by the cross walls, is an effluent collector formed by half tile of concrete, with slotted openings for admission of the filtered water. The two lines of tile unite for each filter, allowing the filtered water to flow through a short length of 16-inch pipe and via an automatic rate controller into the effluent gullet situated between each two rows of filters. Each filter outlet is equipped with an hydraulically operated valve. The main effluent gullets terminate in 7-foot steel conduits leading to an 11-foot steel, con-

crete-cased head conduit, through which the water passes on to the slow sand filters.

For washing the filters, water and air are used, and a separate system of piping is provided. Filtered water is pumped into an elevated wash-water tank, built of reinforced concrete, from which a 48-inch wash-water line leads to the plant, a 30-inch branch line from which extends through the pipe gallery between each two rows of filters. At the center of each filter there is a 20-inch wash-water take-off controlled by a hydraulic valve. This 20-inch line extends longitudinally through the filter, being hung from the roof above the central gutter, and divides at the center of the bed into four 12-inch distributing pipes, from each of which two 8-inch down pipes take off, leading to 8-inch manifold headers placed above the filtered water collectors (below the sand and gravel). The manifold proper consists of 1½-inch lateral pipes, spaced 5¾ inches on centers and drilled with 3/16-inch holes on the bottom. This effects an essentially equal distribution of the wash water under the gravel, which, rising upward through the sand, cleanses the same of its collected impurities, the dirty wash water overflowing into the collecting troughs, thence to the central gutter, and out into the wash-water drain, which consists simply of the space between the filter walls and the effluent gullet. Air agitation is used during washing, being supplied by an air main in each gallery, with branches to the individual filters connected into the wash-water header, the same manifold being used for distributing wash water and air. A 6-inch valve is provided for draining each filter.

Fig. 29 shows a section through one of the filter galleries. At each side are the front walls of opposite filter units. The filter floor is carried through as the gallery floor. In the center, extending longitudinally through the gallery, is the effluent gullet or flume, 6 by 6 feet in area, into which the filtered water discharges through an effluent controller. The top of this flume supports the 30-inch wash header and above that the operating platform. The air pipe is suspended from the ceiling, and at each filter a 12-inch branch is taken off connecting into the 20-inch wash-water pipe. The air supply is controlled by a 12-inch hydraulic valve. The spaces between the filter walls and effluent gullet form the wash-water drains, and the central gutters and drain pipes discharge directly into these.

This plant is of special type, designed for a definite purpose, namely, to prefilter the water only, and the design is not adapted for more general use. The plant was designed and constructed



CROSS SECTION THROUGH FILTER HOUSE

Engineering Record, November 14, 1908.

FIG. 29.—Torresdale Filtration Plant.

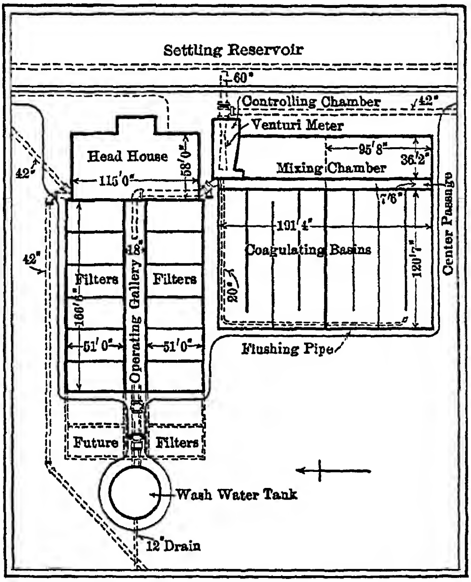
under the direction of Mr. Fred C. Dunlap, chief of the Bureau of Water, Philadelphia, Penn.

The Mechanical Filtration Plant at Minneapolis, Minn.* This plant is of interest as being typical of the modern installation of larger size, because of its flexibility of operation, made necessary by the rapid variations of the Mississippi River, from which the

* *Engineering Record*, November 18, 1911.

raw-water supply is derived, and because of its method of handling and mixing chemicals.

The filtration plant is built near two old service reservoirs, each of 47,000,000 gallons capacity. One of these was built up 10 feet and adapted as a preliminary settling basin, to which the raw water is pumped and allowed to settle (approximately 24 hours)



Engineering Record, November 18, 1911.

FIG. 30.—Minneapolis Filtration Plant. General Plan.

before reaching the filtration plant. The other reservoir was roofed over with a groined arch construction of reinforced concrete, and serves as a clear-water reservoir, receiving the effluent of the filter plant and equalizing the load on the filters, a very desirable feature. The normal rating of the plant is 39,000,000 gallons per day.

The general layout of the plant is shown in Fig. 30. After passing through the preliminary settling basin, the water flows through a 60-inch cast-iron line to a controlling chamber, entering the same through a Venturi meter, which measures and records the volume and actuates the chemical feed controls, causing an automatic adjustment of the amount of coagulant to the raw water

to be treated. The controlling chamber is provided with sluice gates, so that the raw water may pass from it either into the mixing chamber or directly into the coagulating basins; other sluice gates provide for passing it directly to the filters or allowing some of it to waste through a 20-inch cast-iron pipe line intended for flushing sediment from the floor of the coagulating basins.

Normally the water passes from the controlling to the mixing chamber, the coagulant solutions, aluminum sulphate and lime (when required) being introduced at this point. The mixing chamber is a covered structure of reinforced concrete, 34 feet 8 inches wide by 173 feet long inside, with wooden baffles of the vertical type, 3 feet center to center. The water passes back and forth between the baffles in its journey through the mixing chamber, traveling a total distance of about 2,000 feet. This insures a thorough mixing of the coagulants with the water and allows time for the chemical reactions to take place. The mixing chamber is built across the ends of the coagulating basins, with a space of about 7½ feet between the two, this space being denoted on the drawing, Fig. 30, as the *center passage.* This center passage is divided by horizontal diaphragms of concrete into two flumes or conduits, the side wall of the mixing chamber and the end walls of the coagulating basins forming the vertical sides of the flumes. The lower flume receives the water from the mixing chamber and introduces it into the coagulating basins. As it may not always be desirable to run the water through the full length of the mixing chamber, four sluice gates are located in the west wall of same, communicating directly with the lower flume and thence with the coagulating basins. As already stated, the water may enter the lower flume at the north end, directly from the controlling chamber, thus by-passing the mixing chamber. The upper flume receives the water after its passage through the basins and conducts it to the filters. It may also receive the water directly from the control chamber or after its passage through the mixing chamber. Further gates provide for by-passing either basin, or operating the basins both in series or parallel. The extreme flexibility and absence of complicated pipe work in this arrangement are commendable. Below the central passage is a 12-inch sewer into which both the mixing and controlling chambers and the coagulating basins may be drained.

After passing through the mixing chamber, the treated water

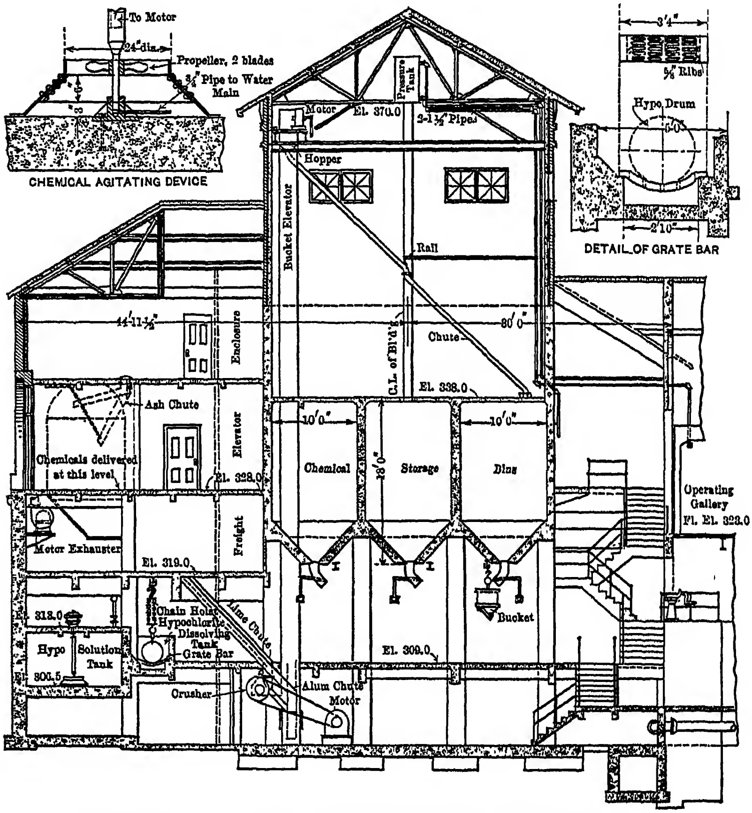
enters the coagulating basins. These are in duplicate, each measuring 95 feet 8 inches by 119 feet 4 inches inside, and have a combined capacity of about 2,800,000 gallons. Each basin has three vertical concrete baffles with water passages around the ends, so that the water makes four passes in traversing the basin. The basins can be flushed by by-passing raw water from the controlling chamber through the 20-inch flushing line already mentioned, being drained off through sumps leading to the 12-inch cast-iron drain under the central passage. Additional fire-hose connections are provided for hosing out the heavy sludge.

The water, after passing through the coagulating basins, enters the upper flume over a skimming weir, through which it passes into a 60-inch influent pipe, leading to the filters. These are twelve in number, six on either side of the operating gallery, and have each a capacity of 3,250,000 gallons at a rate of 125,000,000 gallons per acre per day. Each bed is divided into two parts by central wash-water gutter of the usual type, which, in conjunction with eight lateral gutters, serves to distribute the settled and treated water entering the filter through a twenty-inch valved branch connection from the 60-inch influent header in the gallery.

The filtering medium consists of 30 inches of sand having an effective size from 0.35 to 0.44 mm. and a uniformity coefficient of 1.65. The strainer system consists of concrete ridges cast on the bottom of the filter at right angles to the central gutter. The grooves between the ridges are filled with graded gravel and a brass screen is bolted over the gravel to prevent displacement while washing. The gravel rests on perforated brass strainer plates, below which are water passages for collecting the effluent and distributing the wash water. The filtered water collected by the strainer system flows into a manifold of collector pipes, and through these and a rate controller into the clear-water basin beneath the filters.

The filters are washed by forcing filtered water under pressure upward through the strainer system. No air is used, the wash pressure being sufficient to thoroughly agitate and cleanse the sand. The rate of wash is 15 gallons per square foot per minute. The dirty wash water is collected by the cross troughs and flows into the central gutter, thence through a valved connection into a reinforced concrete sewer beneath the filter gallery. As no large sewer was available, the dirty wash water is collected in a receiving

basin, and slowly drained away through a 12-inch sewer. Water for washing is obtained from an elevated tank of reinforced concrete, located above the receiving basin just mentioned. The capacity of this tank eliminates the necessity for large wash pumps, as it can be filled between washings by relatively small pumps, in

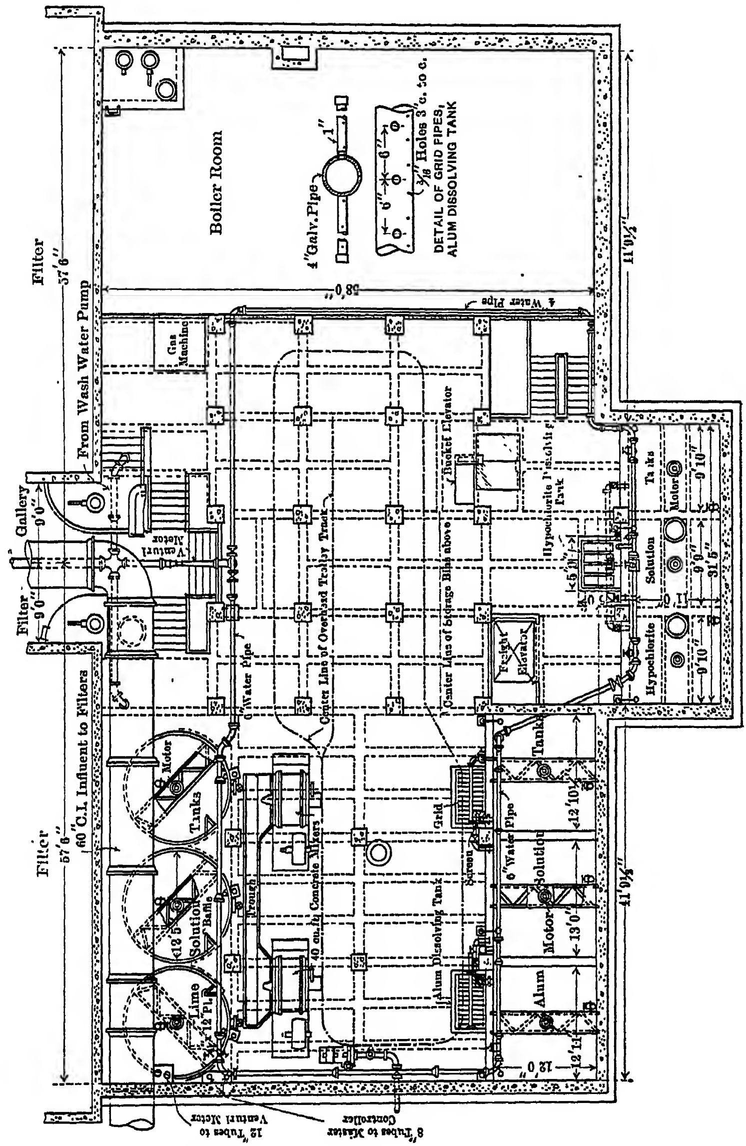


SECTION THROUGH CHEMICAL STORAGE BINS AND DETAIL OF AGITATOR.
Engineering Record, November 18, 1911.

FIG. 31.—Minneapolis Filtration Plant.

the present case by two centrifugals of 1,600 gallons per minute capacity.

Special interest attaches to the arrangements for handling and mixing chemicals. The necessary apparatus is contained in a head house located across one end of the filter building. The



Engineering Record, November 18, 1911.

FIG. 32.—Minneapolis Filtration Plant. Plan of Head House.

floor elevations are such that the chemicals can be handled and stored by gravity, but the solutions must be pumped to the orifice boxes which feed them into the mixing chamber.

The lime and alum are purchased in carload lots and carted to the plant by wagons. The wagons discharge upon a dumping platform shown on the left-hand side of Fig. 31, at elevation 328.0. The lime and alum pass from this platform through separate chutes to the boot of a bucket elevator, the lime passing en route through a small crusher, which breaks it into lumps of a size readily handled by the elevator. The material is raised by the elevator into a hopper at the top of the building and discharges through a grain chute equipped with a revolving spout capable of discharging into any one of 12 reinforced concrete storage bins. In event of a breakdown in the bucket elevator, a freight elevator of standard design may be used to raise the chemicals from the unloading platform to the top of the storage bins, into which they are then shoveled by hand labor. Below the bins a traveling bucket operates on a suspended rail and serves to convey the coagulant to the solution tanks. The arrangement of the tracks is shown in Fig. 32. The traveling bucket is balanced on a scale beam, enabling the operator to measure out the required amount of chemical directly from the bins.

The lime-slaking apparatus is rather unique, consisting of two concrete mixers, each of 1½ yards capacity, into which the lime is dumped directly from the traveling bucket. Water is added and the mixture revolved in the drum of the machine. The milk of lime discharges into a trough having valved outlets into each of the three lime solution tanks. These are circular steel tanks, 12 feet 5 inches in diameter and 13 feet deep. Steel is used, because calcium hydroxid has a destructive action on concrete. The alum and hypo tanks, however, are of concrete and rectangular in plan. The agitating device employed in each of the several tanks consists of a helicoidal bronze impeller mounted on a vertical shaft driven by a motor at the top of the tank. The direction of rotation is such as to create a downward current at the center of each tank, driving the solution along the floor of the tank and up the sides. This course of the solution is further aided by a conical baffle placed over the impeller.

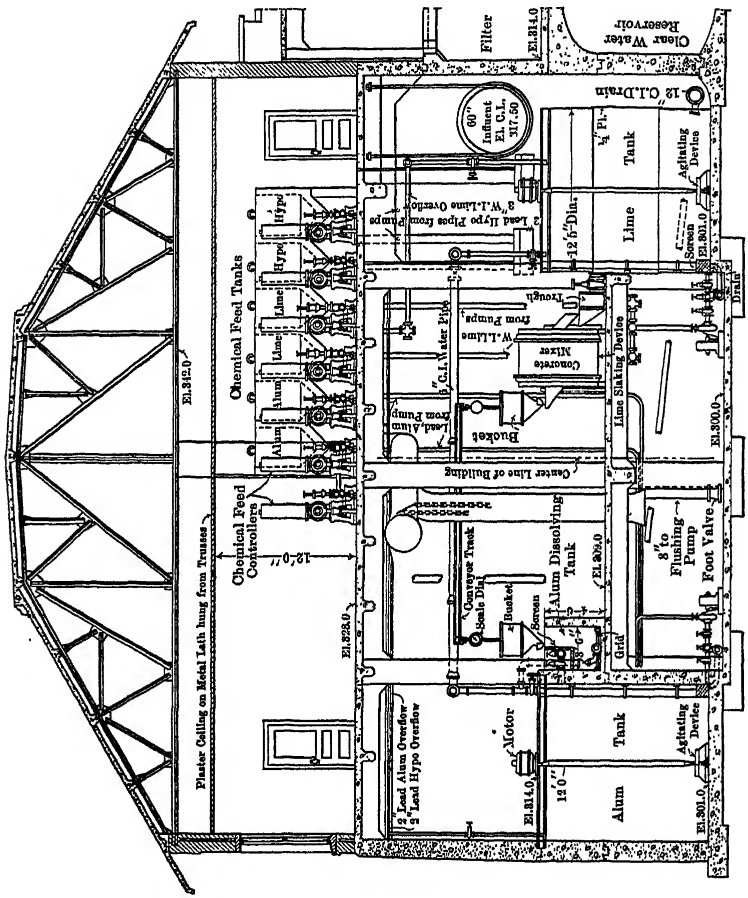
The aluminum sulphate is dissolved previous to discharge into the solution tanks in concrete dissolving boxes, 6 by 3 feet in plan.

and 4 feet deep, which are provided in duplicate. Agitation in these boxes is provided for by a manifold of 1-inch galvanized pipe at the bottom drilled with $^3/_{16}$-inch holes 3 inches on centers. Water flowing upward through this grid dissolves the alum more readily than the usual downward stream. The dissolved alum overflows from these boxes and passes into the solution tanks through a screened opening.

An attempt is made in this plant to overcome the hardship which usually attaches to the handling of the hypochlorite of lime used for disinfection of the filtrate. The device used is shown in Fig. 31. The hypo is received in drums weighing about 750 pounds. The drums are lowered to the operating floor by means of the freight elevator and rolled under an I-beam traveler, running across the hypo dissolving boxes. The drum is lifted into the dissolving box by means of a set of chain blocks, coming to rest on a false bottom of perforated grate bars. The dissolving box is then filled with water so as to submerge the drum completely. While the drum rests on the grate bars, holes are driven in both ends by steel pins; a single pin embedded in one end of the dissolving box is driven into the exact center of one end of the drum, while the other end is perforated by four pins mounted on a chuck rotating on a steel shaft passing through the end of the dissolving box by means of a stuffing gland. Besides its rotary motion, the shaft can move longitudinally through the gland and the can is perforated by striking the end of the shaft with a sledge, causing the four pointed pins in the chuck to perforate one end of the drum, and driving the drum bodily against the center pin at the other end. The drum can now be rotated by turning the shaft through agency of a ratchet and is cut in two under water by a large can opener. The hypo is then dissolved out by the same type of manifold device used in the alum dissolving boxes and flows into the hypo solution tanks.

As the coagulant leaves the solution tanks at a level much below that of the water in the mixing chamber, it is pumped to chemical control devices by small bronze centrifugal pumps. The chemical feed tanks are located on the ground floor. The solutions are pumped into them at a constant rate, a uniform head being maintained by overflows in the tanks which carry the surplus back into the respective solution tanks. The chemical feed controllers consist of adjustable orifices automatically regulated

by the difference in head of the Venturi meter in the controlling chamber, so that the amount of coagulant is always proportional to the rate of raw-water pumpage. The lime is applied as the



Engineering Record, November 18, 1911.

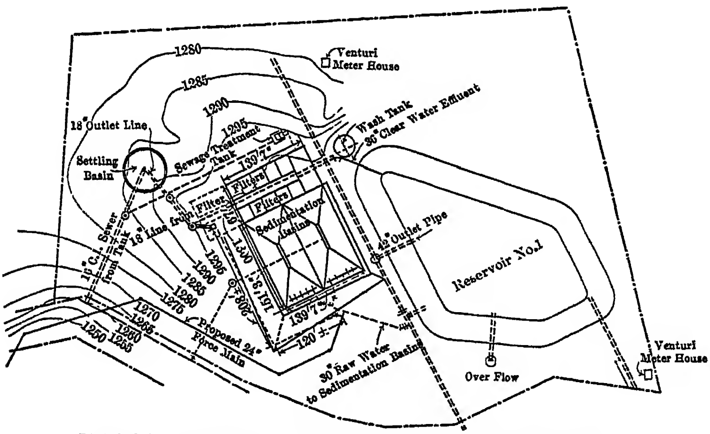
FIG. 33.—Minneapolis Filtration Plant. Solution Tanks, Overhead Conveyor, and Controllers.

water enters the mixing chamber, the alum a little later at some point in the central passage. The hypo is added as the water enters the clear-water reservoir.

This plant was designed by Hering & Fuller, consulting en-

gineers, New York. Mr. Andrew Rinker, city engineer, had supervision of the construction with Mr. W. N. Jones in direct charge, assisted by Mr. J. A. Jensen, waterworks engineer. Mr. J. W. Armstrong had immediate charge of plans and specifications for the consulting engineers.

The Mechanical Filter Plant at Wilkinsburg, Penn.* This is a type of plant peculiarly adapted to very hilly or semi-mountainous regions where the location is adjacent to a high pressure reservoir and rather difficult of access. In this instance the plant is located on a hill top about one mile from the Allegheny River (the source of supply) and about 600 feet above same. The water is pumped directly from the river to the sedimentation basins against a total pressure of 250 pounds per square inch.



PLAN OF MECHANICAL FILTRATION PLANT, WILKINSBURG, PA.

Engineering Record, October 1, 1910.

FIG. 34.

The plant comprises two uncovered sedimentation basins of reinforced concrete, each 150 feet long, 60 feet wide, and 22½ feet deep, and 10 filter beds, each having a capacity of 1,250,000 gallons per day, making the total plant capacity 12,500,000 gallons daily.

The water enters the sedimentation basins through cast-iron manifolds terminating in 6-inch aerating pipes, and is collected at the outlet end of the basins by a reinforced concrete flume connecting with a cast-iron pipe which delivers the coagulated and

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* *Engineering Record,* October, 1910.

settled water to the filters. The general arrangement of plant is shown by Fig. 34.

The filters are housed in a long brick building, being arranged five on each side of a central pipe gallery. The equipment is of standard design. The effluent and wash-water manifold is entirely of cast iron with cast-iron laterals and brass strainers, and above this are placed 8 inches of gravel and 36 inches of sand. Air agitation is used, the air manifold being *below* the gravel and consisting of small perforated brass tubes supplied through a central header pipe. The wash-water troughs are of cast iron, extending laterally from a central gutter of the usual type and are designed to handle 10 gallons of wash water per minute per square foot of sand area. The effluent controllers are of the velocity type, similar in principle to the one previously described. All valves are hydraulically operated, the handles for each filter being grouped on an enclosed marble operating table. This table also contains the loss-of-head gage, which is of the registering type, two pens recording the head on the filter and the draft on the effluent pipe upon a moving chart, clock-driven. Fig. 35 shows a general view of the operating gallery and tables. The interior walls are of buff fire-flashed brick and the whole presents a very neat and sanitary appearance. In the general office, a marble sample table is located on which are mounted glass tubes and spigots, one for each filter, and one each for the raw and treated water. Sample streams from the respective sources are kept constantly circulating through these by individual ½-inch centrifugal pumps, so that the operator has constantly on view and on tap water from all the units of the plant. The effluent discharges through the controller into a reinforced concrete conduit leading to Reservoir No. 1.

At the east end of the filter building and integral therewith is the head house, having three floors: a basement, level with the pipe gallery, a main floor at the operating platform level, and a second floor. The basement contains piping; air, wash, and pressure pumps, sampling pumps, electric generating and heating plants. The main floor contains the solution tanks and orifice boxes, the main entrance or lobby, general office, and laboratories. The office and laboratories are floored and wainscoted with white tile and have a steel ceiling. The lobby contains the stair well, leading to the basement and second floor, the main switchboard, and the more important gages.

Courtesy Pittsburgh Filter Manufacturing Company.

FIG. 35.—Wilkinsburg Filtration Plant, Interior of Filter House.

The second floor is devoted to storing, handling, and mixing the coagulants. The upper ends of the solution tanks, located on the floor below, project through to this level for charging purposes. Lime, alum, and hypo tanks are provided in duplicate, each being equipped with a concrete solution box having a screened outlet into the tank. Owing to the isolated location of the plant, the chemicals must be brought up by wagons, which deliver at one end of the head house. The barrels or sacks of coagulant are handled by means of a trolley or I-beam traveler, the track for which is suspended from the ceiling of the second floor and extends through an opening in the end wall similar to a hay-trolley on a barn. The hoisting is done by an electric motor which is mounted directly on the trolley traveler.

A novel method is used for handling the air and water for washing. Small motor-driven centrifugal wash pumps and rotary air pumps in duplicate are located in the basement and these deliver into the combined air and wash-water tanks shown in Fig. 36. This is really a gasometer, the lower tank holding the wash water and serving to seal the upper inverted air tank, which rises and falls as the volume of air contained varies. This enables small wash and air pumps to be used, running about 50 per cent of the time, and allows the electric generating plant to be kept down to a reasonable size. These pumps shut off automatically when the tank fills up, and start after the water and air levels drop a certain amount.

As it is expensive to pump water up to the plant, the dirty wash water is collected in a settling basin, and after the silt settles out is repumped into the sedimentation basins, by automatically controlled centrifugal pumps.

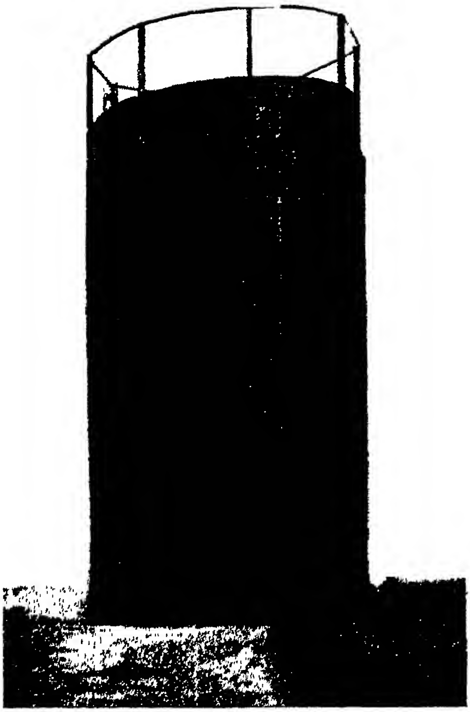
The generating plant is of 30 kilowatt capacity, gas-engine driven. The heating plant is of the usual steam-boiler type.

This plant was installed by the Pennsylvania Water Co., W. C. Hawley, chief engineer and superintendent. Mr. J. N. Chester, of Chester & Fleming, Pittsburgh, was consulting engineer. The Pittsburgh Filter Manufacturing Co. furnished and installed the equipment.

The Filtration and Softening Plant at Columbus, Ohio.* The Columbus filtration plant is an excellent example of an in-

* *Engineering Record,* February 24, 1906.

stallation designed to soften as well as to filter the water. The source of supply is the Scioto River, which drains a region underlain with dolomite (mixed calcium and magnesium carbonate), and consequently the water is quite hard, the total hardness being



Courtesy Pittsburgh Filter Manufacturing Company.

FIG. 36.—Wilkinsburg Filtration Plant, Combined Air and Wash-Water Tank.

about 250 parts per million, and the incrustants averaging about 100 parts per million. The treatment given the water reduces the total hardness to 80 and the incrustants to about 40 parts per million. The capacity of the plant is 30,000,000 gallons per day. The water is treated with lime to precipitate the bicarbonates of calcium and magnesium, then with soda ash to remove the incrustants, and finally alum is added as a coagulant, although

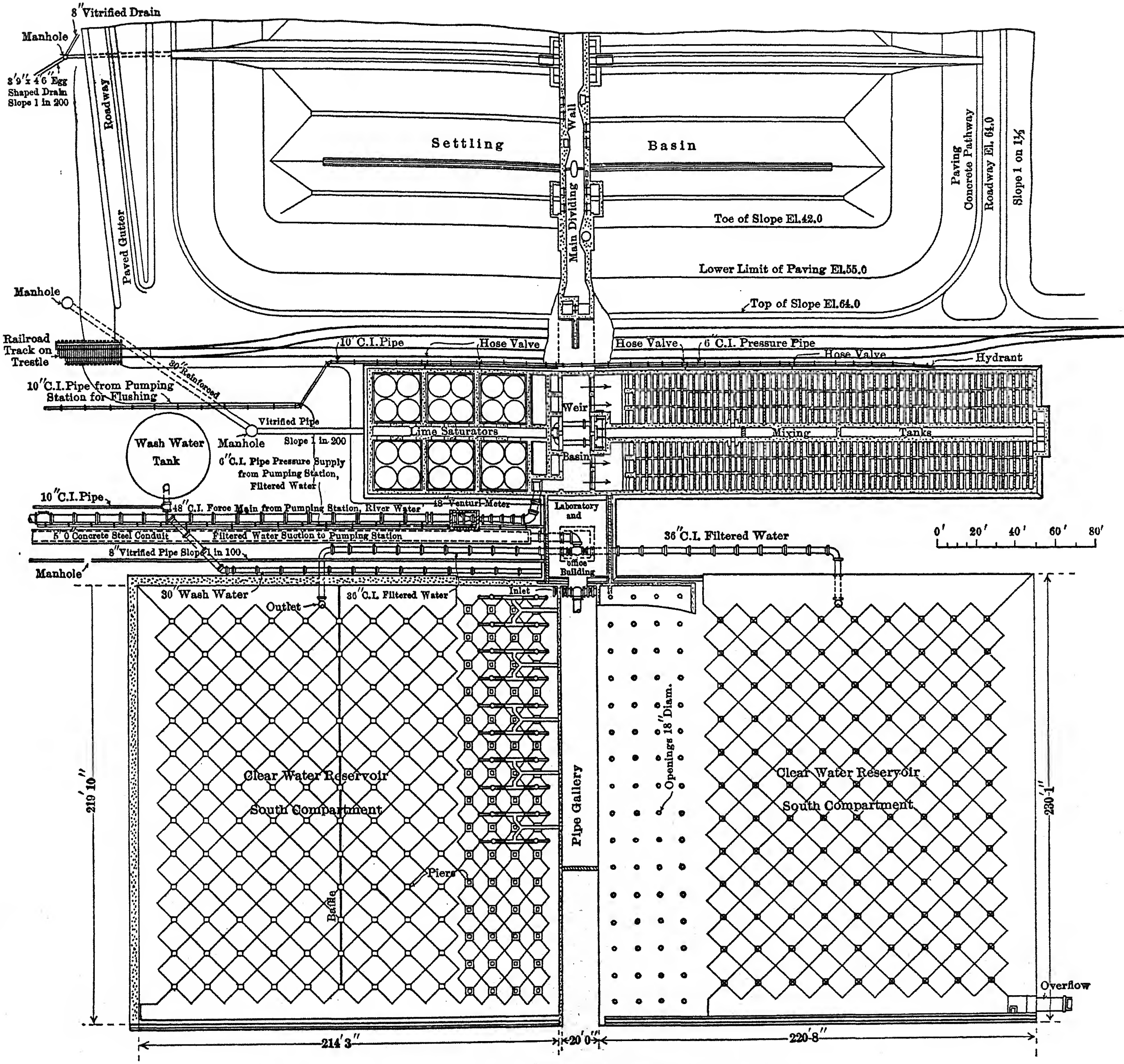
an effort is made to utilize the gelatinous magnesium hydroxid formed in the softening process for this purpose.

The general layout of the plant is shown in Fig. 37, referring to which it will be seen that the water enters a weir basin (which forms the first floor of the head house), through a 48-inch cast-iron main, passing through a Venturi meter immediately before entering this basin. Besides recording the rate of pumpage of the raw water, this meter also controls the rate of discharge of the coagulant solutions, varying this in proper ratio to the raw-water pumpage.

Along the sides of the weir basin are adjustable weirs, of which there are three sets of two each, for diverting certain proportions of the raw water to lime saturators, soda trough, and mixing tanks. The plant was designed so that a maximum of 25 per cent of the raw water passed over the weirs to the lime saturators, a similar amount over the soda weir, and the remaining 50 per cent passed over the weirs into the mixing tanks. An additional weir was provided for feeding untreated water to the effluent of the settling basins, to eliminate any caustic alkalinity of the settled water due to overtreatment with lime; and an overflow weir, slightly higher than the rest and leading to the settling basins, takes care of undue fluctuations in the raw-water pumpage.

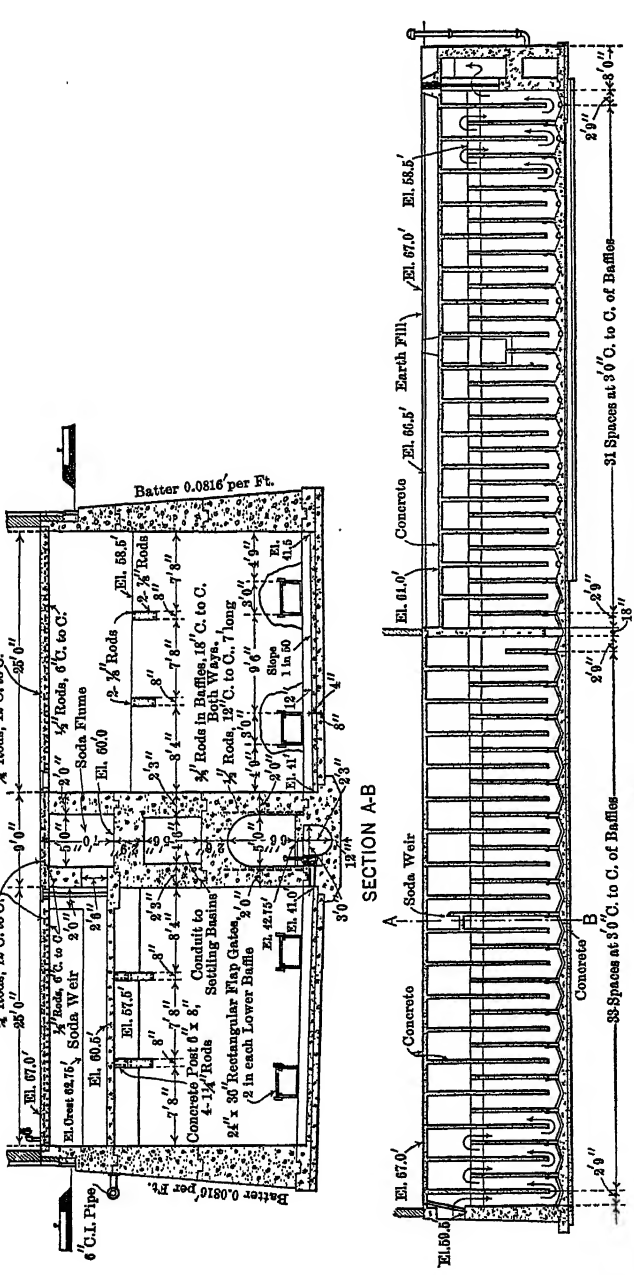
To the portion passing over the lime weirs, milk of lime is supplied by means of a perforated pipe, after which the water passes into the six lime saturators by means of a central flume with a branch pipe into each saturator. Within the saturator tank each pipe divides into four branches, which distribute the lime and water evenly over the bottom of the tank. The water rises slowly in the tank, being constantly stirred by revolving paddles (four sets per saturator), and overflows into a central flume between the two rows of saturators and above the entrance flume. Thus the water and lime are intimately mixed, giving a saturated solution of lime water (about 60 grains per gallon). The lime-saturated water flows through the flume and a cast-iron pipe beneath the weir basin and enters the mixing tanks together with the main body of water.

The purpose of the mixing tanks is to bring about a thorough mixture of the water with the softening reagents, thereby greatly facilitating the reactions. These tanks have a total capacity of nearly 1,000,000 gallons, so that the water requires almost an hour to pass through them. They are two in number,



Engineering Record, February 24, 1906.

FIG. 37.—Columbus Filtration Plant, General Plan.

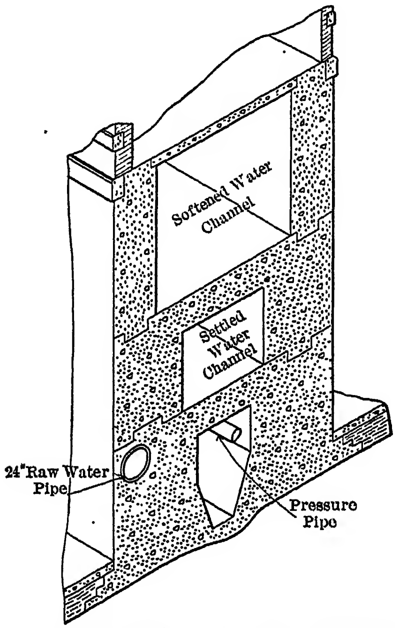


LONGITUDINAL AND TRANSVERSE SECTIONS OF MIXING TANKS

Engineering Record, February 24, 1906.

Fig. 38.—Columbus Filtration Plant.

arranged on either side of a central gallery, which contains the conduit for carrying the mixed water to the settling basins, the flume for introducing the soda ash (as will be explained presently), and the mixing tank blowoffs for drainage and cleaning. The mixing tanks are fitted with vertical baffles spaced 3 feet on centers, causing the water to take a circuitous course, passing over one



Engineering Record, February 24, 1906.

FIG. 39.—Columbus Filtration Plant.

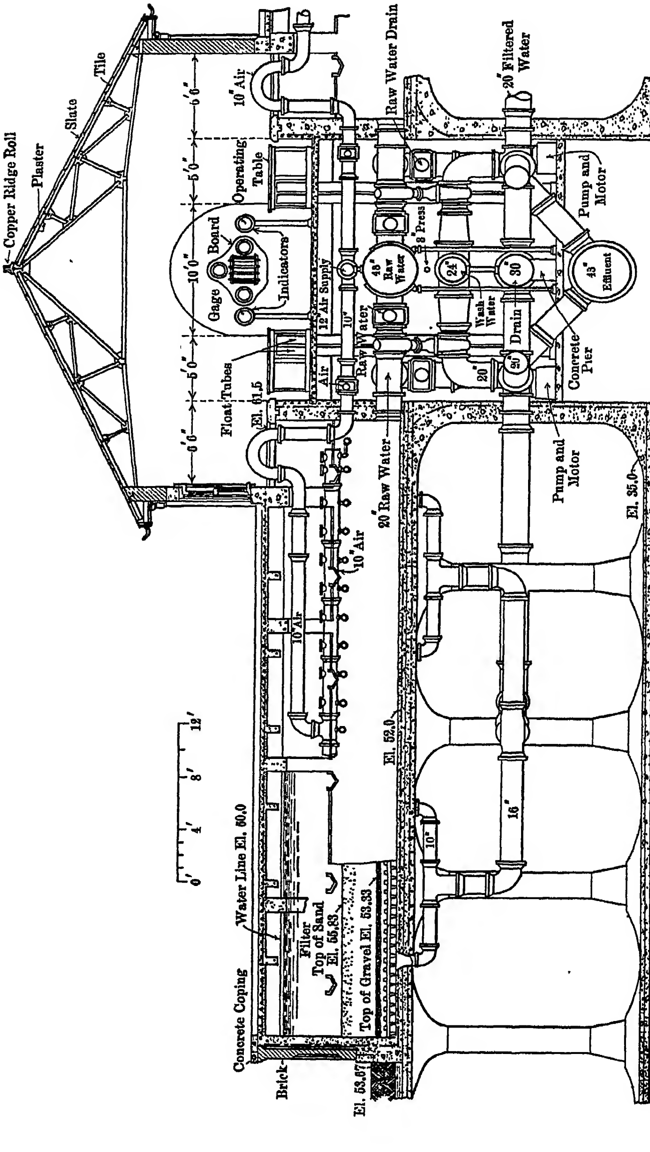
baffle and under the next. Sluice gates into the receiving conduit are provided at intermediate points, so that a shorter period of mixture can be obtained if desired.

The soda ash is introduced into its quota of water as this is passing over the soda weirs, and travels through a flume at the top of the gallery between the mixing tanks, entering these at a point 60 feet from the weir basin, via an overflow weir extending across both tanks. The construction of the mixing tanks is shown by Fig. 38.

The treated and thoroughly mixed water passes on to the

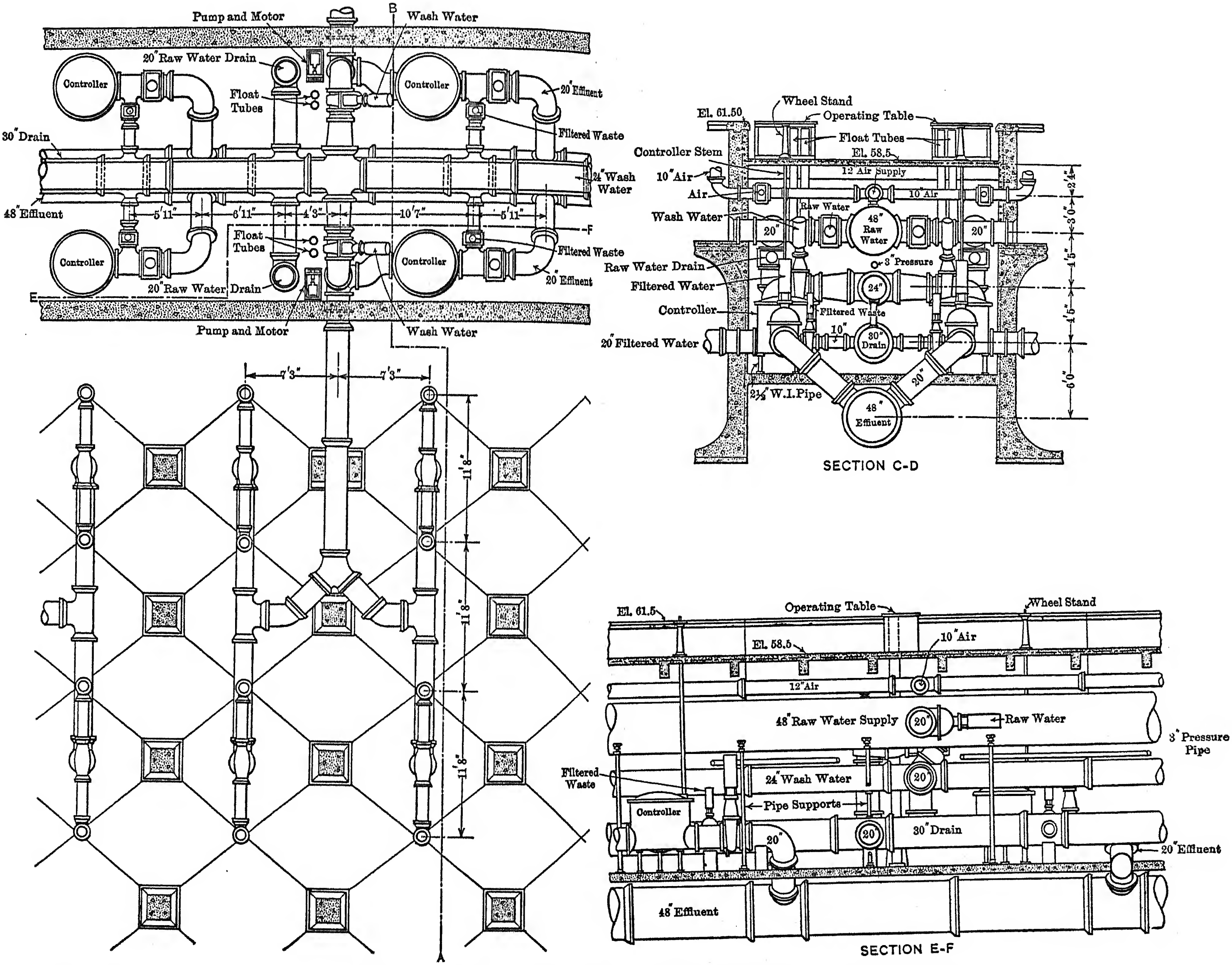
settling basins, which have a capacity of 15,000,000 gallons, or a period (nominally) of 12 hours. Through the settling basins extends a dividing wall, which is cored out as shown by Fig. 39 to form three flumes or gullets, the upper carrying the softened water to the basins, the middle carrying the settled water from the basins to the filters, and the lower being used to drain the basins and containing the blowoff valves. The upper level of this wall serves as a gate-house, containing the sluices controlling the admittance of water to and withdrawal from the basins, and is enclosed in a brick superstructure. Laterally the basins are further subdivided by walls so as to form, in all, six compartments. Each compartment has a vertical baffle through the middle, extending from the main dividing wall to within 60 feet of opposite end, compelling the water to make a complete circuit of the compartment, *i.e.*, leaving the softened-water flume it would travel outward from the main dividing wall laterally in both directions to the far end of the baffles, around these, and then back to the dividing wall, repeating the process for each compartment. The water in each half of the basin would, therefore, make six complete passes across the basin before reaching the settled-water conduit at the outer end of the dividing wall. It is also possible to distribute the water so that each compartment of the basin takes its quota of the water, making essentially six smaller settling basins, each receiving one-sixth of the water. This would reduce the velocity through the basins to one-third of the normal. Any compartment can be shut down, drained, and flushed by pressure hoses.

After passing through the settling basins, the water is carried to the filters through the settled-water flume. There are ten filter units, each of 3,000,000 gallons per day capacity. They offer no novel points not already described. Fig. 40 gives sections through one of the filters and the pipe gallery. The settled water enters the gallery by means of a 48-inch "raw-water" pipe, with 20-inch branches entering the units at the central gutter. The water is filtered through 30 inches of sand (effective size, 0.4 mm., uniformity coefficient, 1.5), and through a layer of graded gravel (from $\frac{1}{16}$ to 1 inch in size). A detail of the strainer system is shown by Fig. 42. The ridges shown are $8\frac{3}{4}$ inches on centers, and the brass strainer plates in the valleys are similarly spaced. The filtered water is collected by a pipe manifold and passes via a rate controller and effluent pipe to the clear-water reservoir.



Engineering Record, February 24, 1906.

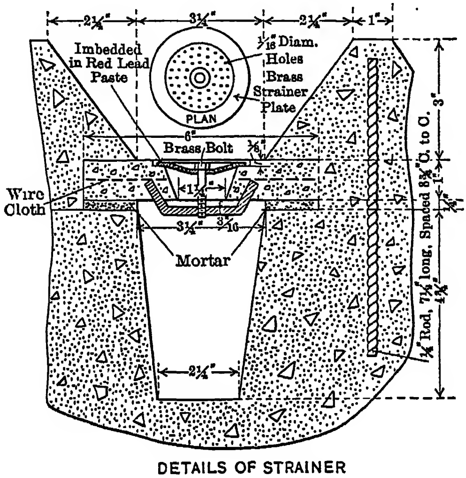
FIG. 40.—Columbus Filtration Plant. Section Through Filter Building.



Engineering Record, February 24, 1906.

FIG. 41.—Columbus Filtration Plant. Details of Piping in Filters and Pipe Gallery.

Wash water is supplied from a reinforced concrete tank and delivered to the filters by a 24-inch line passing through the pipe gallery with 20-inch branches into each unit. It is distributed throughout the filter unit by means of the strainer system. After rising upward through and cleansing the sand, it is removed by



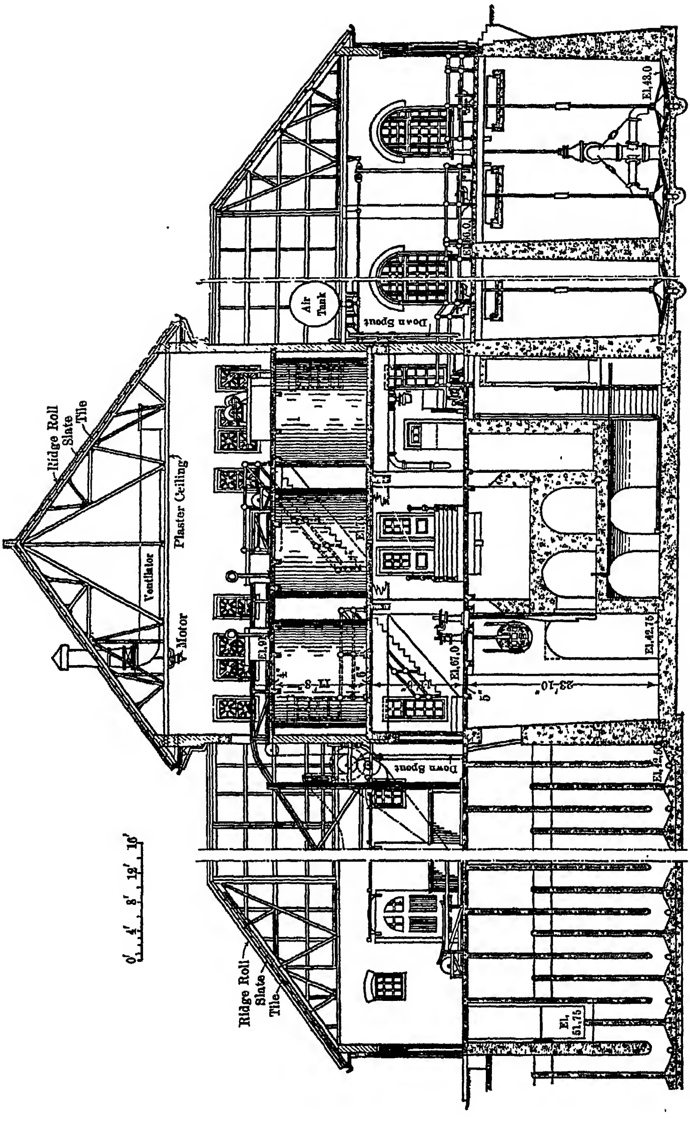
Engineering Record, February 24, 1906.

FIG. 42.—Columbus Filtration Plant.

six lateral gutters in each half of the filter, leading into the central gutter, and is thence carried away by a 30-inch drain in the filter gallery. The plant is designed to give a rate of wash of 8 gallons per square foot per minute.

In addition to water, air is used for agitation before or during washing, and for this purpose a system of air pipes and manifold is provided. There is a 12-inch air-supply line in the gallery, with 10-inch branches to each filter. These branches are hung along the central gutter, and outlets in the bottom connect with lateral pipes supported on the concrete ridges which hold down the gravel. These laterals are 1 inch in diameter, made of brass and spaced 8¾ inches apart. They are drilled on the bottom with ⅛-inch holes, 8¾ inches center to center. The air system is designed for a maximum rate of 3 cubic feet of air per square foot per minute.

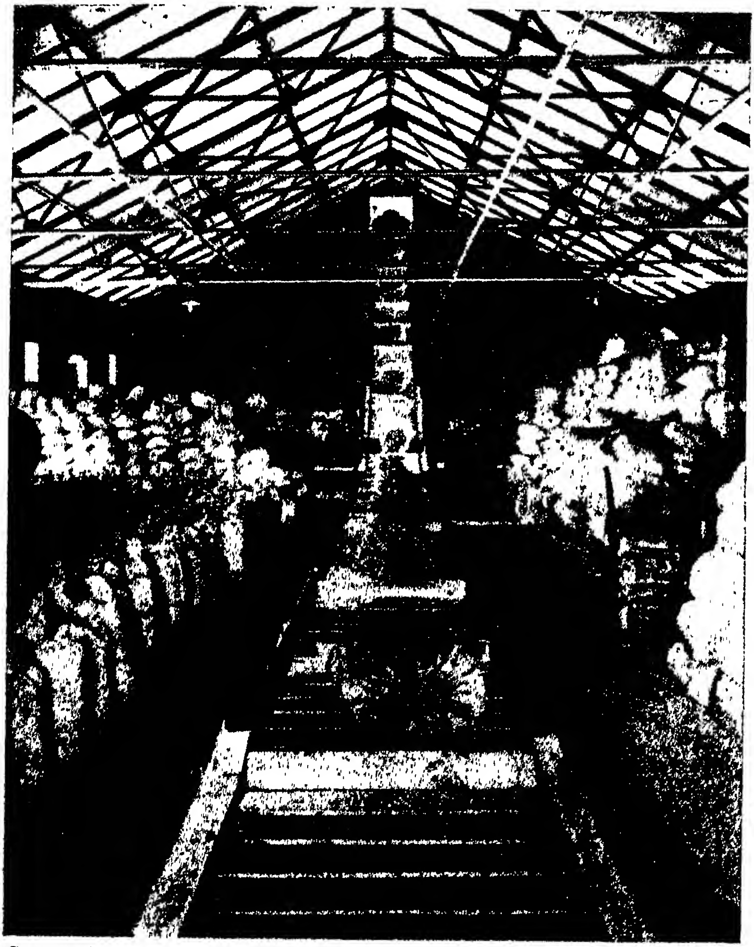
All valves in the operating gallery are hydraulically controlled,



Engineering Record, February 24, 1906.

FIG. 43.—Columbus Filtration Plant. Section Through Storage, Head, and Saturator Houses.

the levers for each unit being grouped on a marble table, which also contains the loss-of-head gage. Each filter is further equipped with a small pump and motor, which draws water from the ef-



Courtesy Charles P. Hoover, Chemist in Charge.

FIG. 44.—Columbus Filtration Plant. Raising Lime Bags by Continuous Elevator.

fluent pipe and discharges it into a small bowl on the operating table, so that a sample of filtered water from any unit can be readily obtained.

A one-story superstructure entirely covers the top of the mixing tanks and serves as a storage house for lime, soda ash, and alum. The chemicals are received in carload lots, generally in bags, there being a railroad siding on each side of the storage house, which has unloading platforms and side doors similar to a freight station. The capacity of the storage house is 900 tons, or about 20 carloads. An apron conveyor, running centrally the entire length of the storage house, and driven by an 18-horse-power motor, serves for carrying the bags of chemicals to the third floor of the head house, where the solutions are made up.

The second floor of the head house is almost completely filled by the chemical-solution tanks, of which there are nine, three each for soda, coagulant (alum or ferrous sulphate), and lime. The tanks are of reinforced concrete, circular, 12 feet 6 inches in diameter and 11 feet 5 inches deep. The coagulant and soda solutions are kept uniform by agitation with compressed air, an air grid of brass piping in each tank distributing the air uniformly. In the lime tanks, revolving paddles on a centrally mounted vertical shaft serve the same purpose. The tanks are provided with the customary piping for carrying the solutions to the orifice boxes, and for draining, and each tank is equipped with a float gage for recording the depth of solution.

The tops of the solution tanks support the third floor of the head house. Here are located the devices for making up the chemical solutions. The apron conveyor enters through the wall of this building adjacent to the storage house and traverses it centrally for about two-thirds the length, at which point the head pulley of the conveyor is located. Bags of chemicals, if not removed previously, are therefore dumped automatically at this point. As the amount of lime used exceeds that of alum and soda, it is delivered in this way, and the slaking tanks are located conveniently to the end of the conveyor. They are three in number, 6 feet in diameter and 2 feet 8 inches deep, built of reinforced concrete. Hot water is used in slaking, and the lime and water are stirred during the process by motor-driven vertical rakes. The slaked lime is discharged into the lime-solution tanks already described. There are two dissolving tanks each, for coagulant and soda ash, conveniently located along the sides of the conveyor. These tanks are of concrete, rectangular in plan, 5 feet long, 3 feet wide, and 2 feet 8 inches deep. The material

to be dissolved is placed on a screen about 3 inches above the bottom of the tank, and water (which may be heated) is passed upward through it, overflowing a weir and passing into the solution tanks. Scales for weighing are provided, and a chute is located at one end of the building by means of which empty sacks are returned to the storage room, where they are packed for shipment to the chemical-supply company.

The chemical solutions are fed to the raw water automatically in proportion to its amount by orifice boxes controlled through the Venturi meter in the raw-water main.

The plant contains the usual offices, bacteriological and chemical laboratories, a locker room, lavatory, and storeroom.

Soon after commencing operation the method of handling lime was found to be unsatisfactory. The bags of lime varied as much as 15 pounds from the standard weight, and on storage they air-slaked and broke open. Thereafter the lime was bought in bulk and sacked at the plant, which proved a disagreeable and unsatisfactory method. To overcome these difficulties, a system of conveyors and automatic scales was installed and put into service in 1913.*

Referring to Fig. 45, it will be seen that a large overhead storage bin, having a capacity of 220 tons, was built over one of the sidings adjacent to the head house. The lime, being received in bulk, in carload lots, is fed into a hopper by means of a power shovel operated by a man in the car. From this hopper the lime is fed to a bucket elevator by a screw feeder and lifted into the bin. To supply the solution tanks, the lime in the storage bin is fed to the elevator through a chute from the bin bottom and is lifted to an overhead screw conveyor, which carries it to any of three smaller hoppers suspended over the three lime-slaking tanks. Each of these hoppers feeds into an automatic weighing device, electrically controlled, which weighs out a predetermined quantity of lime at regular intervals into the slaking tanks, whence the lime solution travels through the solution tank and orifice box to the raw water as already described.

The weighing device consists of an equal-armed scale (like a chemical balance in principle), to one arm of which the desired weight is attached, while the other suspends a receptacle to receive

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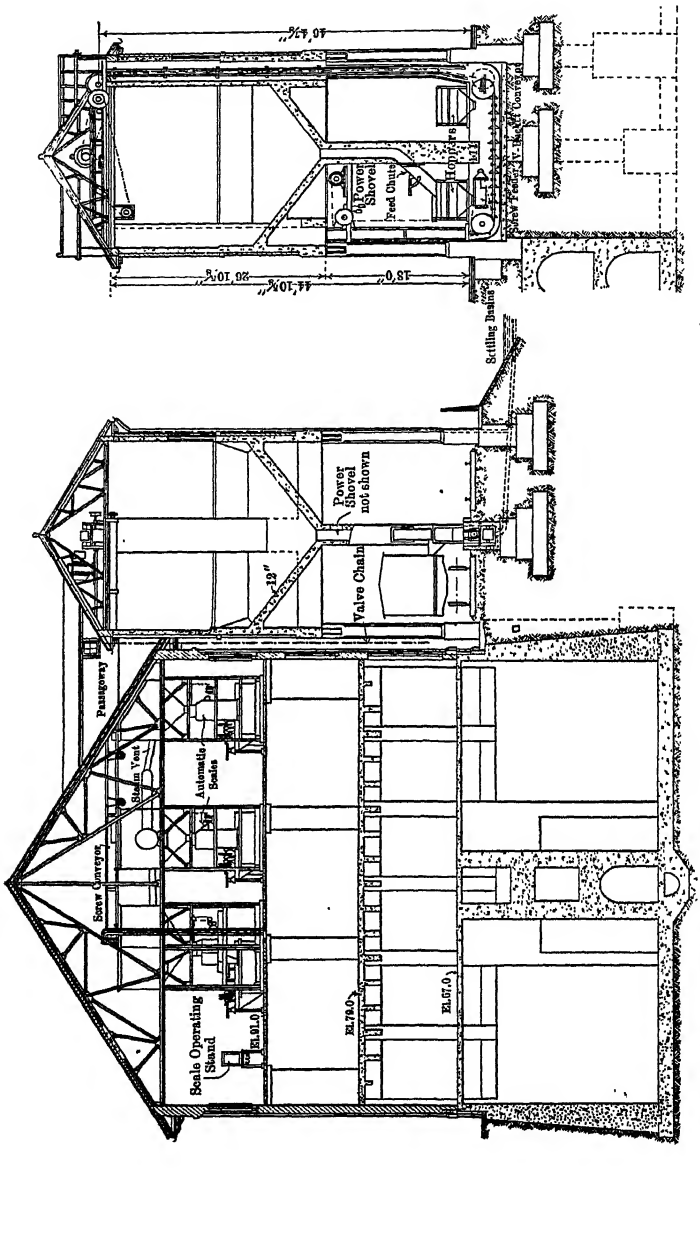
* Annual Report, Division of Water, Columbus, O., 1913.



Annual Report of Water Department, Columbus, O., 1913.

Fig. 45.—Columbus Filtration Plant. Section Through New Lime-Handling Equipment.

the lime from the hopper above. The tilting of the beam, when the proper amount is weighed out, automatically closes a gate in the bottom of the hopper. The charge is dumped into the slaking tank through an opening in the bottom of the receptacle, the gate to which is opened at the proper time by an electromagnet.

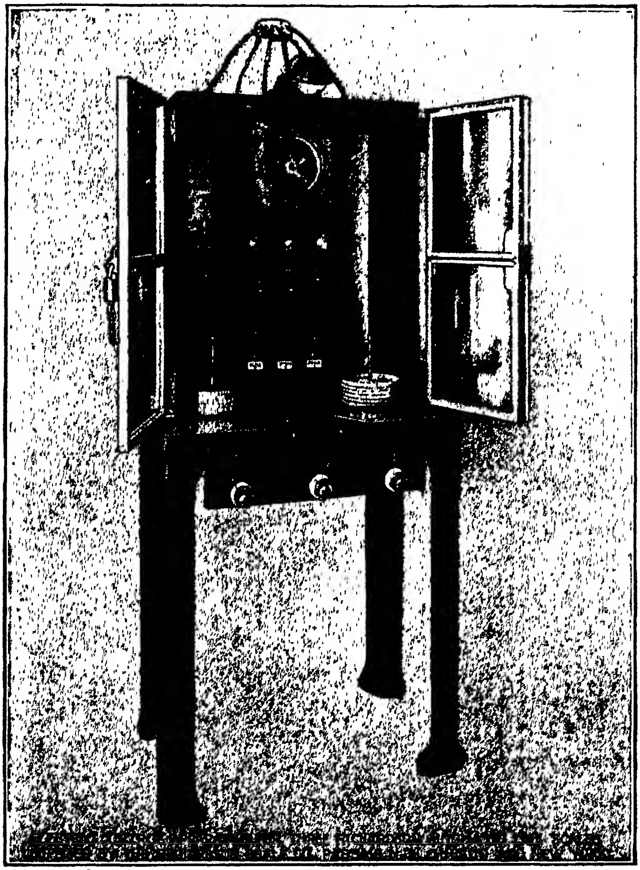
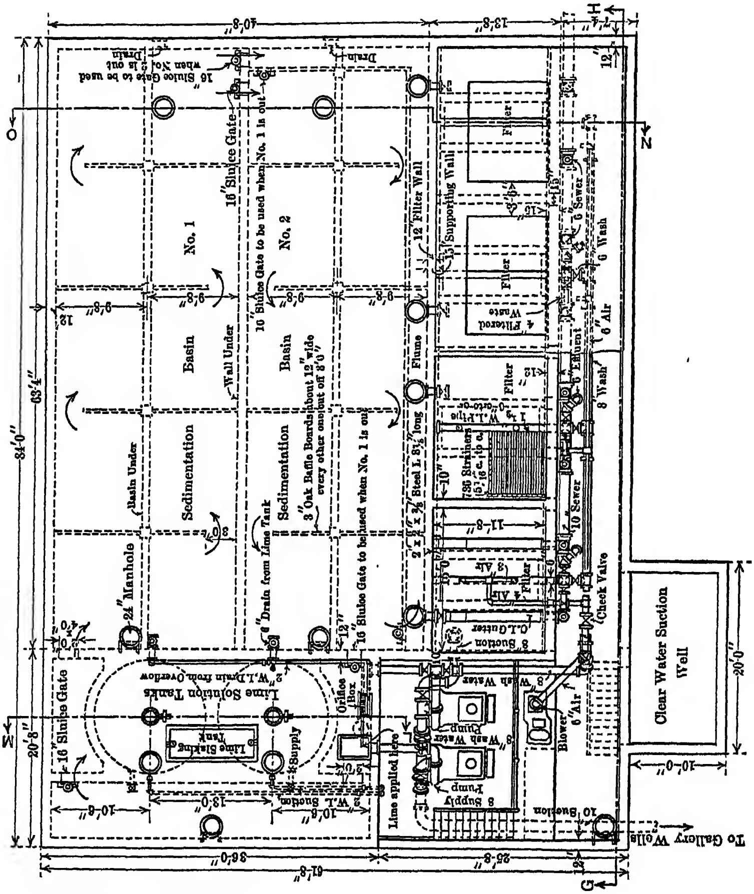


FIG. 46.—Columbus Filtration Plant. Timing Device for Automatic Scales.

The electric circuit controlling the dumping is closed by the clock device shown in Fig. 46. A clockwork gives a uniform rotative movement to a circular disk with contact points on its periphery. Every time a contact is made, the electric circuit actuating the magnet in the weighing device is closed, and a charge of lime is

dumped. Different disks are used to give any desired interval between contacts. A number of these are shown in the right and left hand corners of the case containing the apparatus. Switches are provided to throw any of the three weighing devices into

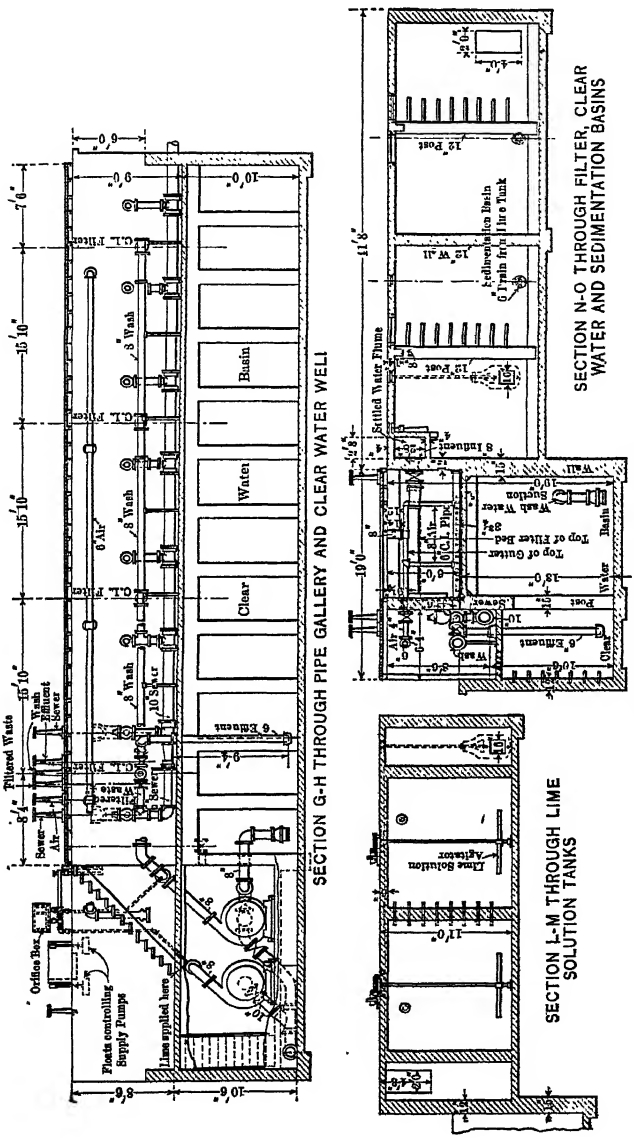


Engineering Record, July 23, 1910.

FIG. 47.—Iowa City Iron Removal Plant. General Plan of Purification Works.

operation and electric lights in series with the circuits indicate that these are unbroken by lighting up with each discharge.

The original design and construction was carried on under direction of Messrs. Julian Griggs and Henry Maetzel, succes-



Engineering Record, July 23, 1910.

FIG. 48.—Iowa City Iron-Removal Plant.

sively chief engineers of the Board of Public Service. Mr. John H. Gregory was engineer in charge and Messrs. Rudolph Hering and George W. Fuller were consulting engineers. The later improvements were carried out by Messrs. Charles P. Hoover, chemist in charge, and C. J. Clarke, engineer of the water-works department.

The Iron-Removal Plant at Iowa City, Ia.* The mechanical filter plant requires no especial adaptation in order to remove iron successfully. If in the bicarbonate form, the addition of lime, followed by sedimentation of sufficient duration to allow of complete reaction between the lime and bicarbonates, and filtration to remove the precipitate, will eliminate the iron very readily. Sometimes a coagulant is added to hasten precipitation. Such a plant is in successful operation at Iowa City, Ia. The water supply is obtained from galleries in the bed of the Iowa River, and contains from 3.5 to 4.3 parts per million of iron.

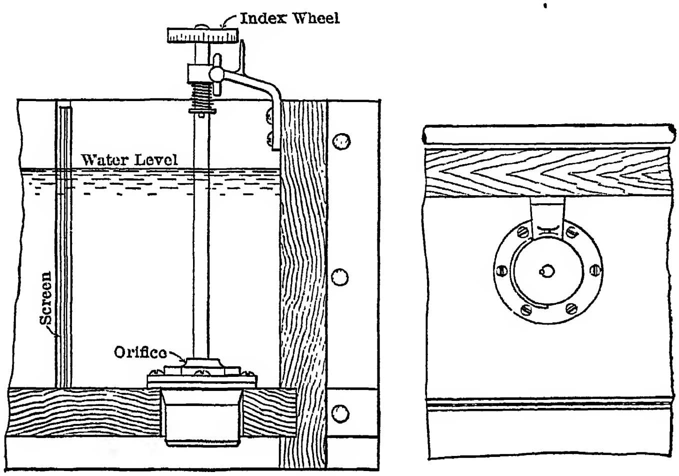
The mechanical filter plant consists of lime-dosing apparatus, settling basins, and filters of 2,000,000 gallons per day capacity. The water is raised from the galleries to the settling basins by centrifugal pumps, steam driven. Lime solution is applied near the point of entrance into the basins. The basins, two in number, are of 250,000 gallons capacity. The water takes a circuitous route through these and enters a flume extending along the rear of the filters, as shown by Fig. 47. In this case, as in the Torresdale plant, the settled water enters the filters at the rear through valved branches from the flume. While this simplifies construction, it has the opposite effect on operation. Each filter contains one cast-iron wash trough through the center, by way of which the settled water is also introduced and distributed. The filtering material consists of 28 inches of sand of the usual size, supported on 12 inches of graded gravel. The collector manifold consists of a single 6-inch cast-iron header extending longitudinally through the center of the filter with 1½-inch wrought-iron laterals on either side, spaced 6 inches center to center. Brass strainer heads are tapped into these laterals, 5 7/16 inches on centers.

The filters are washed in the usual way, both air and water being used. Wash water is supplied by an 8-inch centrifugal pump at the rate of 7.5 gallons per square foot per minute, the dirty wash water overflowing into the central trough and being

* *Engineering Record*, July 23, 1910

led into a sewer. Air is used in the customary manner, being distributed through the same manifold as the wash water.

Two lime-solution tanks, 12 feet in diameter and 10 feet 6 inches deep, are located along one end of the settling basins. The lime is slaked in a concrete box, 3 feet wide, 9 feet long, and 2 feet deep, placed on the floor above the solution tanks, and is discharged

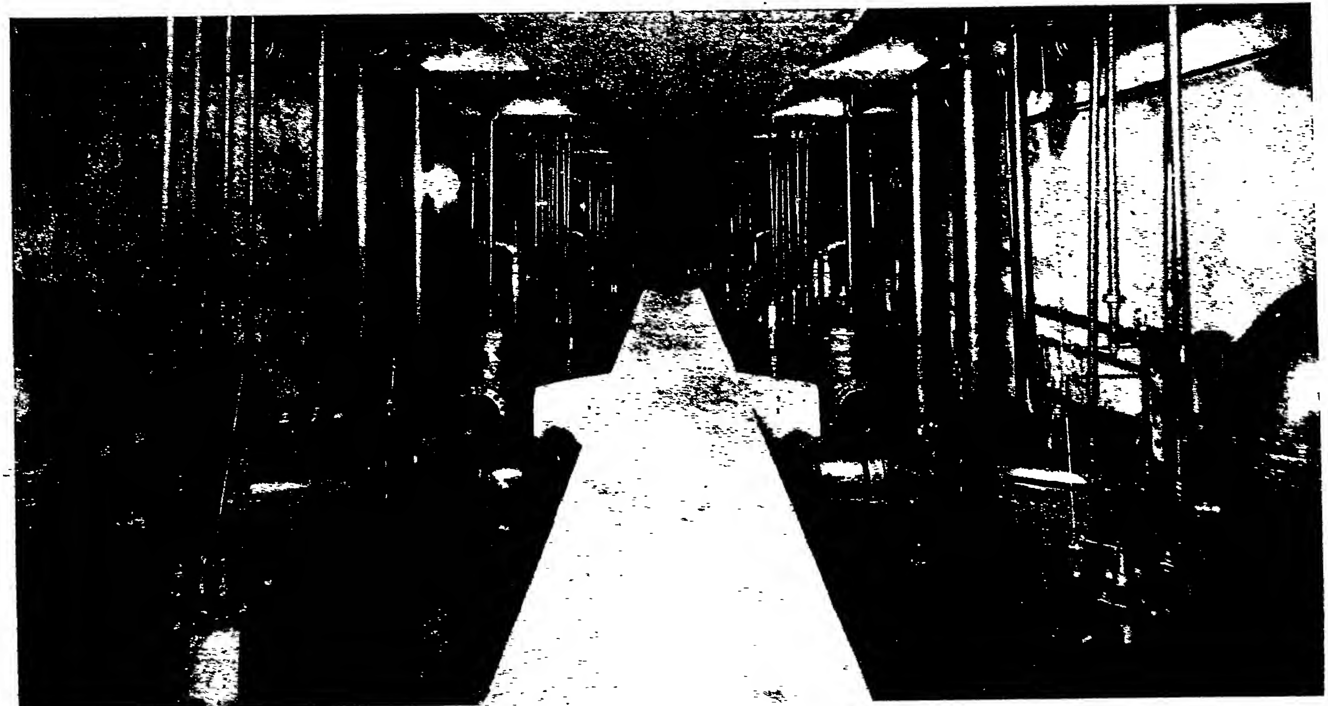


Engineering Record, July 23, 1910.

FIG. 49.—Iowa City Iron-Removal Plant. Lime-Solution Orifice.

into the latter through sluice gates at both ends of the box. The lime solution is kept uniform in strength by means of revolving paddles in the solution tanks. Pipes from these tanks lead to two 1½-inch bronze centrifugal pumps, which raise the solution to an elevated orifice box, through which it is discharged into the raw-water main. Fig. 49 shows a detail of the orifice box. The orifice consists of an annular slot in a rubber disk, the opening of which can be varied by means of a revolving sector turned by a vertical shaft. An index wheel at the top of the shaft indicates the relative size of the orifice. A constant head is maintained by means of an overflow weir discharging back into the solution tanks. A clear-water basin is located below the filters.

The plant is of reinforced concrete construction with brick superstructure. As it was built for a special purpose and at a minimum cost, it does not possess the flexibility and ease of operation desirable in the average plant. This plant was designed and built by the New York Continental Jewell Filtration Company.



Courtesy Pittsburgh Filter Manufacturing Company. *Filtration Plant, Flint, Mich., Wm. G. Clark, Engineer.*

A Typical Pipe Gallery.

CHAPTER III

PHYSICAL AND CHEMICAL TESTS

Tests must be made in connection with water purification in order to ascertain those qualities of the raw water affecting its treatment, to measure the improvement effected by purification, and to make sure that the filtrate is up to the standard of purity.

It is not necessary to make a complete analysis of the water, in fact, it is not desirable, as to do so would occupy much valuable time, which could be better employed outside of the laboratory. It is of greater importance that the determinations herein outlined be made with sufficient frequency to include all possible variations in the condition of the raw water, in general not less than once a day.

The usual tests to be made are as follows:

In the Raw Water:	In the Filtrate:
Taste and odor	Taste and odor
Turbidity	Turbidity
Color	Color
Alkalinity or acidity	Alkalinity
Free carbonic acid (CO_2)	CO_2
Iron	Free alum or ferrous sulphate
Bacterial count at 20° Cent.	Iron
Bacterial count at 37° Cent.	Bacterial count at 20° Cent.
Coli determinations	Bacterial count at 37° Cent.
	Coli determinations

Of these, color may be omitted in waters where this quality is of small moment, and iron except in the case of waters containing an appreciable amount. The remaining tests are necessary in order to keep well informed on the condition of the raw and filtered water.

In carrying out the following tests, great care should be observed, in order to insure accurate results. The apparatus used should be clean, and immediately before use should be wiped out with a clean cloth and then rinsed out with distilled water of

known purity. This is best accomplished by means of a *wash bottle*, Fig. 50. This consists of a liter flask, with rubber stopper perforated for two glass tubes as shown. By blowing into the mouthpiece, a fine stream of distilled water can be directed on apparatus requiring to be rinsed. Glass tubing for making this and other apparatus can be cheaply bought and bent to the desired shape by heating to redness in an ordinary gas flame. The tubing can be cut with a small triangular file, by nicking and then breaking it, the cut ends being rounded in the gas flame. Apparatus should be thoroughly rinsed and dried after use. Occasionally it should be cleaned with the solution described in Chapter IV, being thoroughly rinsed afterward to remove all traces of fluid.

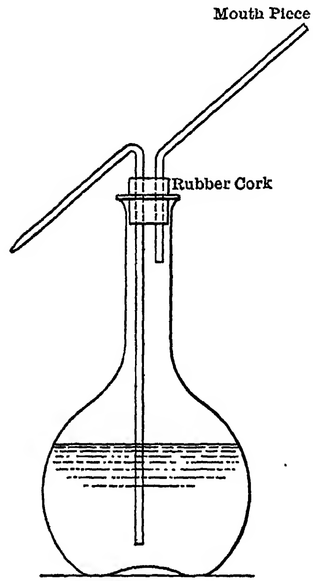


FIG. 50.—Wash Bottle.

Care must be used in measuring samples to obtain the exact amount required, as well as in reading the burettes and observing the end point in tests involving indicators. Needless to say, samples should be collected in clean bottles, and before testing it is well to rinse the mouth of the sample bottle by pouring out and wasting some of the water contained. If distilled water is not available, the apparatus should be washed out before use with some of the water to be tested.

A supply of distilled water is very desirable for laboratory use. The bottled "distilled" water on the market is often untrustworthy and should not be accepted as reliable until proved by the tests given in this chapter, especially those for CO_2, alkalinity, and iron, which should all give negative results. More thorough tests are given in Appendix B. If possible the water should be distilled in the laboratory. The apparatus required is shown in Fig. 51. The water to be distilled is placed in the boiler (*a*), generally made of copper, tin-lined, and is evaporated by means of a Bunsen burner

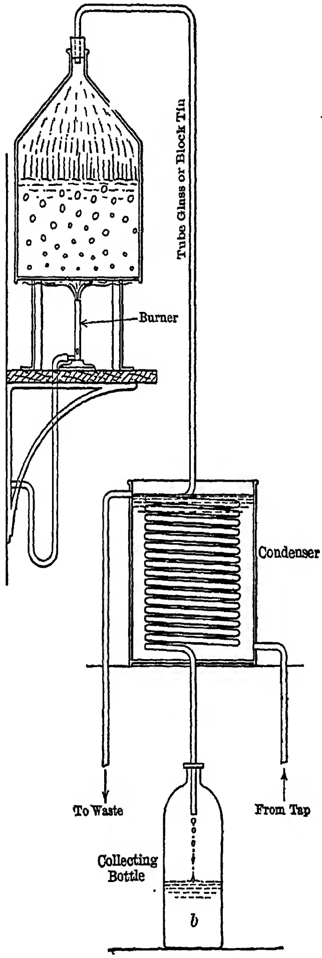


FIG. 51.—Water Still.

placed below the boiler. The steam passes off through the block tin tube into a "worm" or condenser of the same material, immersed in a tank of cold water, causing it to condense. The distilled water is collected in the bottle (*b*). A constant supply of cool water is kept circulating about the worm by means of a hose connection from the tap, and a waste overflow, generally carried by a hose to the sink. The first portion of the distillate caught by the bottle (*b*) should be used to rinse out same and then be wasted. Distilled water greedily absorbs CO_2 and oxygen from the air, and, if desired to be free of these, should be freshly boiled. The laboratory supply of distilled water is conveniently kept in the container shown by Fig. 52. It consists of a large glass carboy, loosely corked, with a siphon made of glass and rubber tubing. The water can be pulled over into the siphon by suction and will then continue to flow whenever the pinch-cock is opened until the carboy is empty.

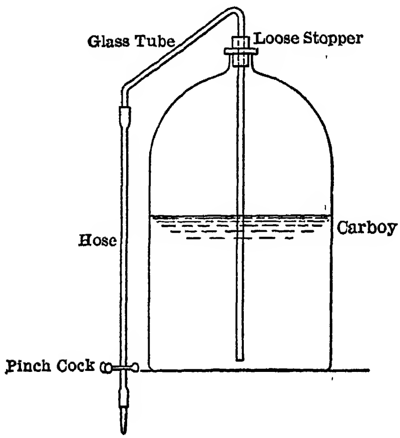


FIG. 52.—Distilled-Water Container.

It is suggested that those inexperienced in making chemical preparations obtain the reagents and standard solutions required in the following tests from a competent chemist or chemical supply house. Those wishing to prepare their own standard solutions will find directions in Appendix B.

Extreme care should be used in handling and preserving standard solutions. They should be kept in hard glass, glass-stoppered bottles, except sodium carbonate, the container for which is preferably rubber-stoppered. The bottles should be kept closed at all times to prevent the entrance of impurities or evaporation of the solution. The stoppers when removed should never be laid on their sides, nor should the mouth of the bottle be carelessly handled. Before opening, the mouth and neck of the bottle should be wiped free of dust with a *clean* dry cloth. In

transferring solutions to bottles or burettes, the latter should be perfectly clean and dry. A small amount of the solution should then be poured into the bottle or burette, and used to rinse the same thoroughly, being then poured out. After this preliminary rinsing the bottle or burette may be filled with the solution. Burettes should be fitted with a small glass cap, or else corked, when not in use, to prevent evaporation. It is not advisable to keep a large stock of standard solutions on hand, as these deteriorate, it being preferable to make or have made new solutions at intervals of a few months. Where large amounts of solutions are used, a *standard* may be prepared with especial care, and kept for comparative purposes, the solutions used being made up to the required strength by titration with this standard. A $\frac{n}{50}$ solution of sulphuric acid is well adapted for this purpose and will keep a long time. Then to prepare a $\frac{n}{50}$ solution of sodium carbonate dissolve the approximate amount required (see Appendix B) in a liter of double-distilled water and titrate 10 cc. of this solution with the standard acid, using erythrosin or methyl orange as an indicator. The sodium carbonate solution should be made a little strong, and then diluted down with distilled water until 10 cc. of the standard acid will exactly neutralize 10 cc. of the sodium carbonate solution. An acid solution for general use can now be made, using the sodium carbonate just prepared as a standard of comparison. (In preparing acid solutions, or in diluting strong acids, the acid should always be poured into the water; if this operation is reversed the acid will sputter and fly about and may cause painful and dangerous burns.) To prepare solutions of other concentrations, it is only necessary to vary the ratio of standard solution used in titration. Thus for a $\frac{n}{10}$ solution of sodium carbonate, a sample of 10 cc. should require 50 cc. of the $\frac{n}{50}$ sulphuric acid to neutralize it; for a $\frac{n}{22}$ solution $\frac{50}{22} \times 10$ or 22.7 cc. of the sulphuric acid would be required.

The metric system of measurement is used in chemical and bacterial work. Lengths are measured in meters, decimeters (1/10 meter), centimeters (1/100 meter), and millimeters (1/1000 meter). The symbols for these units are "m.," "cm.," and "mm." respectively. Volumes are measured in cubes of the linear units, thus cubic centimeters (abbreviation "cc."), and cubic decimeters are commonly used, the latter being the unit of liquid measure and being called the "liter" (abbreviation "l."). It follows

that a liter equals 1000 cc. Units of weight are the gram, which is the weight of 1 cc. of water under standard conditions, the multiples being the "kilogram" (1000 grams) and the milligram (1/1000 gram). The abbreviations used are respectively, "gm.," "kgm.," "mgm." The following table shows the relation between units of the English and metric systems.

TABLE

1 inch	=	2.54	centimeters
1 foot	=	30.48	centimeters
1 yard	=	0.9144	meters
1 pound	=	0.454	kilograms
1 ounce	=	28.35	grams
1 grain	=	64.80	milligrams
1 pint	=	0.568	liters

The strength of standard solutions is given as *normal* (abbreviated "N."), or fractions thereof, thus one-fiftieth normal ($\frac{n}{50}$), one-tenth normal ($\frac{n}{10}$). The meaning of these terms is beyond the scope of this book, but can be found in any work on general chemistry.

The apparatus used in the following tests may be obtained from any scientific or chemist's supply house. For measuring out samples a measuring glass or graduate is generally used (Fig. 53). Greater accuracy can be obtained by using a measuring bottle (Fig. 54). This is a long-necked bottle of a size to hold a definite quantity of liquid (50 cc., 100 cc., etc.), when filled to a mark in the glass of the neck. In use, the bottle is filled slightly above the mark and the surplus is removed by smartly jerking the bottle. Where the test involves colorimetric determinations a Nessler tube (Fig. 55) is used, the sample being made up to the mark. For measuring out small quantities of liquid (for instance, the erythrosin in the alkalinity test) pipettes (Fig. 56) are used. These are made to hold 1 cc., 5 cc., 10 cc., etc., up to 100 cc. or more. The pointed end is inserted into the solution and the mouth is applied to the other end, the solution being sucked into the pipette to a little above the mark on the stem. The mouth is then removed and a finger quickly substituted over the upper end. By slightly releasing the pressure of the finger the solution is allowed to run out until it stands just at the mark, after which the finger is tightly pressed over the end and the measured quantity of solution

is removed and discharged into the sample. Needless to say it is inadvisable to use a pipette in drawing off strong acids or poisons, owing to the danger of getting some in the mouth.

Standard solutions are measured out from burettes (Fig. 57). These consist of glass tubes graduated (generally to 1/10 cc.), so

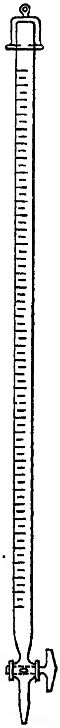


Fig. 57

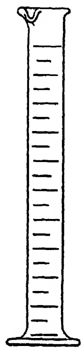


Fig. 53

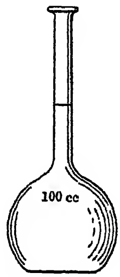


Fig. 54

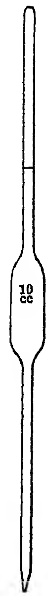


Fig. 56

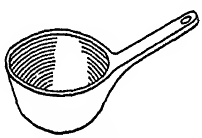


Fig. 58

Fig. 55

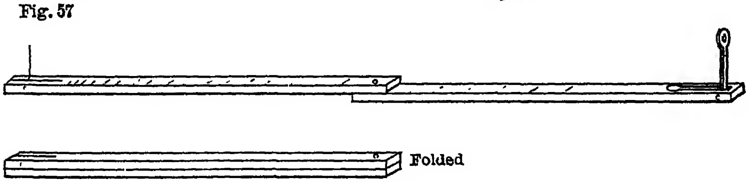


Fig. 59

that the amount of solution run into the sample can be read off. The initial reading (to 1/10 cc.) is taken before the test and after sufficient solution has been run into the sample to produce the required change in color of the indicator the burette is again read,

the difference between the two readings giving the number of cc. of solution used. The glass pet cock at the lower end allows the stream from the burette to be regulated. The small glass bell cap on top prevents evaporation.

The sample during the test may be contained in a glass bottle, a porcelain casserole (Fig. 58), or dish (any white porcelain dish or cup may be used), or in a glass beaker. The latter is simply a container of thin glass (see Figs. 73 and 75 of coagulation, which show typical beakers). Generally a clear drinking glass or bottle may be substituted for a beaker, unless it is required to heat the solution contained.

For special tests of water, other than those given here, the reader is referred to "Standard Methods of Water Analysis," published by the American Public Health Association, or to any standard work on volumetric analysis.

Taste and Odor. Many waters contain mineral constituents or organic matter giving off tastes and odors. The odor of the raw water should be determined cold, that of the filtrate both hot and cold. It is not necessary to taste the water, as the senses of taste and smell are very closely allied.

The cold odor is determined by half filling a large bottle with the water and inserting the stopper. Then shake the bottle vigorously, remove the stopper, and smell the odor at the mouth of the bottle.

The hot odor is determined by heating about 200 cc. of the sample, in a beaker covered with a watch glass, to almost boiling. Allow the beaker and contents to cool for several minutes, remove the watch glass, and smell the odor.

The odor may be described in the report by the following abbreviations:*

v—vegetable	m—moldy
a—aromatic	M—musty
g—grassy	d—disagreeable
f—fishy	p—peaty
e—earthy	s—sweetish

Turbidity. The generally accepted standard for turbidity is that as measured by the turbidity rod of the United States Geological Survey. This, as generally constructed (Fig. 59), is a hard-

* "Standard Methods of Water Analysis." American Public Health Association.

wood rod, half inch by half inch in section, about four feet long, having a platinum wire of 1 millimeter (0.04 inch) diameter inserted at right angles to its length near one end, and an open sight (such as a screw eye) at the other end, 1.2 meters (47¼ inches) from the wire. The wire should project beyond the rod at least one inch. The user places his eye at the sight and submerges the wire end of the rod into the water to be tested at right angles to the surface. The rod is pushed into the water until the wire just disappears, as seen by the observer. The turbidity is measured by the submergence of the rod. A turbidity which causes the wire to disappear with a submergence of 100 millimeters is called 100, other turbidities are marked on the rod as per the following table:

GRADUATION OF TURBIDITY ROD*

Turbidity	Depth of Wire, mm.	Hazen Reciprocal Scale	Turbidity	Depth of Wire, mm.	Hazen Reciprocal Scale
10	794	0.032	160	69	.37
15	551	.046	180	62	.41
20	426	.060	200	57	.44
25	350	.073	250	49	.52
30	296	.086	300	43	.59
40	228	.111	350	39	.65
50	187	.136	400	35	.72
60	158	.160	500	31	.82
70	138	.184	600	28	.92
80	122	.208	800	23	1.09
90	110	.230	1,000	21	1.21
100	100	.254	1,500	17	1.49
120	86	.295	2,000	15	1.72
140	76	.334	3,000	12	2.10

* From the papers of the U. S. Geological Survey.

In this table the corresponding values for the Hazen Reciprocal Turbidity Rod have been given, as this standard was used in making some of the older records and may be convenient in referring back to these.

Turbidity measurements should be made in the open, preferably during the middle of the day and not in direct sunlight. For high turbidities a glass jar about 6 inches in diameter and 8 to 10 inches deep can be used. For low turbidities a tank 3 feet in diameter and 4 feet deep or a barrel is required. Very high turbidities must be diluted in order to obtain accurate results, that is, the sample is mixed with one or more times its volume of clear

water, and the turbidity obtained multiplied by a corresponding factor.

For convenience in laboratory use, "bottle standards" are often prepared* (Fig. 60). Take diatomaceous earth, wash with water to remove soluble salts, and ignite to remove organic matter; treat and warm with dilute hydrochloric acid; wash with dis-

FIG. 60.—Turbidity Standards.

tilled water to remove acid, and dry. Grind and sift through a 200-mesh sieve. Fill a number of clear glass half-gallon bottles with distilled water, and add the prepared diatomaceous earth, testing with the turbidity rod until the desired turbidity is obtained. Or one gram of this powder can be mixed with 1000 grams of distilled water to give a stock suspension having a turbidity of 1000, and the bottle standards prepared from this by dilution. Low turbidities can be obtained by dilution with distilled water. Standards having turbidities of 3, 5, 10, 15, 20, 30, 40, 50, 60, 70, 80, 90, and 100 are generally prepared in this way. The bottles should be kept tightly corked and sealed. The water to be tested is put in a bottle similar to those used for the standards and compared with these, both sample and standard being well shaken before comparison.

* "Standard Methods of Water Analysis." American Public Health Association.

Color. The standard solution for color determination is prepared as follows: "Dissolve 1.246 grams of potassium platinic chlorid ($PtCl_42KCl$), containing 0.5 gram platinum, and one gram crystallized cobalt chlorid ($COCl_26H_2O$), containing 0.25 gram of cobalt, in water, with 100 cc. concentrated hydrochloric acid, and make up to one liter with distilled water."* This

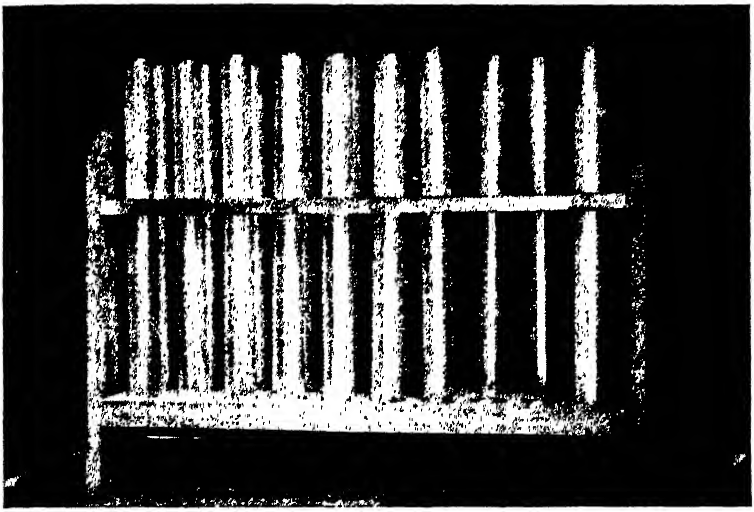


Fig. 61.—Color Standards and Rack.

standard solution has a color of 500 parts per million. Slight variations may be made in the amount of cobalt chlorid to more nearly match the color of any particular water. From the standard solution, dilutions are made with distilled water having colors of 0, 5, 10, 15, 20, etc., up to 70, and these are put into 100 cc. Nessler tubes of such dimensions that the 100 cc. mark comes about 25 cm. above the bottom and is uniform in all the tubes. The solution must be up to the 100 cc. mark and the tubes should be corked when not in use to prevent evaporation and the entrance of dust. The tubes are placed in a vertical position in a "color rack" (which can be obtained from any dealer in chemical apparatus), resting on a white porcelain plate or slab.

The water to be tested is first filtered to remove the turbidity

* "Standard Methods of Water Analysis." American Public Health Association.

and then poured into a 100 cc. Nessler tube similar to those in the rack. For comparison it is placed next to those in the rack, the color being determined by looking downward into the upper ends of the tubes against the white porcelain slab beneath. It is thus compared successively with the various standard tubes, the results

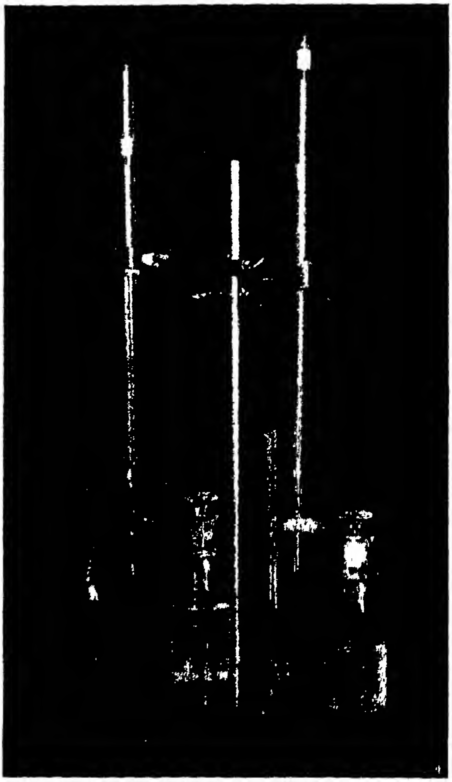


FIG. 62.—Apparatus for Alkalinity Test.

being recorded as that of the standard to which the color of the sample most nearly agrees.

Alkalinity. Apparatus: 1–100 cc. burette, graduated to 1/10 cc. for $\frac{n}{50}$ sulphuric acid (H_2SO_4); 1–100 cc. burette, graduated to 1/10 cc. for $\frac{n}{50}$ sodium carbonate (Na_2CO_3); 1–250 cc. clear glass, wide-mouthed, glass-stoppered bottle; 1–100 cc. measuring glass or flask.

Reagents: $\frac{n}{50}$ sulphuric acid; $\frac{n}{50}$ sodium carbonate; erythrosin solution (0.1 gram of the sodium salt in one liter distilled water); chloroform, neutral to erythrosin.

Procedure: With a graduated glass or flask measure 100 cc. of the sample to be tested into the 250 cc. glass-stoppered bottle,

Fig. 63.—Apparatus for Free Carbonic-Acid Test.

add 1 cc. of erythrosin with a pipette and 5 cc. of chloroform. Cork the bottle and shake well. If the sample has a pink color it is alkaline. In that case titrate with $\frac{n}{50}$ sulphuric acid, adding a little at a time, and shaking well after each addition. Continue to add the acid until the pink color disappears. The number of cubic centimeters of sulphuric acid added, multiplied by 10, gives the alkalinity in parts per million.

In case the sample remains white after adding the erythrosin, it is acid, and should be titrated in a similar manner, using the $\frac{n}{50}$ sodium carbonate. The number of cubic centimeters of sodium carbonate used, multiplied by 10, gives the acidity in parts per million *as* H_2SO_4.

Remarks: For strict accuracy, a correction should be applied for the alkalinity of the erythrosin. This correction can be obtained by running a test as above with distilled water, when the alkalinity obtained will be that due to the erythrosin. In general, this correction is about 1 part per million, to be subtracted for alkaline samples and added for acid samples.

The chloroform used can be recovered by emptying the samples into a wide-mouthed bottle after the test. The chloroform collects in the bottom of the bottle, the water above can be decanted from time to time, and when sufficient chloroform has collected it can be recovered by redistillation.

If the sample is very turbid, it should be filtered before the test, so that the action of the indicator will not be obscured.

Free Carbonic Acid. Apparatus: 1–100 cc. burette, graduated to 1/10 cc. for $\frac{n}{50}$ sodium carbonate· 1–250 cc. porcelain dish or casserole; glass stirring rod.

Reagents: $\frac{n}{50}$ sodium carbonate (Na_2CO_3) and phenolphthalein solution (1 gram in 200 cc. of 50-per-cent alcohol).

Procedure: Pour 100 cc. of the sample into the procelain dish and add a few drops of phenolphthalein. If the water remains colorless it contains carbonic acid. In that case, add sodium carbonate from the burette slowly, gently stirring the water meanwhile. Continue adding sodium carbonate until a faint, permanent pink color appears in the water. The number of cubic centimeters of sodium carbonate added, multiplied by 4.4, gives the amount of free carbonic acid (as CO_2) in parts per million.

Remarks: To obtain accurate results, it is very important that in collecting the sample, carrying it to the laboratory, and in conducting the test, it be as little agitated as possible, since the free CO_2 readily escapes. The stirring rod should be used gently, merely to mix the reagent through the sample. A rubber-tipped stirring rod can be used to advantage.

As in the alkalinity test, a very turbid water can be filtered before the test, but this must be accomplished with the least possible agitation.

In acid waters erroneous results will be obtained, due to the phenolphthalein indicating the acids as well as the CO_2. In such a case, run the test as above outlined, then subtract from the reading in cubic centimeters of sodium carbonate required to obtain a pink coloration with phenolphthalein, two times the number of cubic centimeters required for the acid test with erythrosin, and multiply the remainder by 4.4 to obtain the parts per million of CO_2.

Example: Acidity test with erythrosin required 10 cc. of $\frac{n}{50}$ Na_2CO_3

CO_2 test with phenolphthalein required	25 cc.
2×10 cc. =	20 cc.
Subtracting	5 cc.
Multiplying by	4.4
Parts per million CO_2	22.0

The same result can be obtained by determining the amount of sodium carbonate required with phenolphthalein, then taking a second sample, boiling off the free carbonic acid, and repeating the test. The difference between the two tests, in cubic centimeters, multiplied by 4.4, will give the CO_2 in parts per million.

Swamp waters and others containing weak organic acids may give slightly erroneous results in the above test, but this error is generally relatively unimportant.

By means of Plate I, the results of alkalinity, acidity, and CO_2 tests can be determined graphically from the burette readings. In this chart the necessary corrections for the effect of reagents and the presence of acids in the free carbonic-acid test are made. The chart is ruled with a series of horizontal lines corresponding to the number of cubic centimeters of reagent required in making the test. There is also a series of vertical lines corresponding to the results required in parts per million, as indicated by the figures along the lower margin. Three heavy diagonal lines are drawn across the chart, representing respectively the relation of the desired result in parts per million to the cubic centimeters of reagent used, for the free carbonic-acid test, titrating with one-fiftieth normal sodium carbonate and phenolphthalein indicator, for the alkalinity test and for the acidity test, with (in both cases) eryth-

rosin as indicator, and one-fiftieth normal sulphuric acid and sodium carbonate respectively. The fine diagonal lines in the lower left corner are for use in correcting the carbonic-acid results in acid water. The uses of this chart are best illustrated by examples:

Example No. 1. Alkalinity Test with Erythrosin. In testing a water for alkalinity according to instructions given on page 104, 12.60 cubic centimeters of $\frac{n}{50}$ sulphuric acid are required to discharge the pink color of the erythrosin. Look along the left-hand margin of the chart for the horizontal line corresponding to 12.6. As each horizontal line represents two-tenths of a cubic centimeter of reagent, the required line is the third above the heavy line marked 12. Follow this horizontal line toward the right until it crosses the diagonal line marked "Alkalinity with 1 cc. Erythrosin." This intersection occurs midway between two vertical lines. Following downward between these lines to the lower margin, this is intersected two and one-half spaces beyond the 120 line. As each space on the lower margin corresponds to two parts per million, the result of the test, in parts per million, is 125.

Example No. 2. Acidity Test with Erythrosin. In a test made according to instructions on page 104, 6 cubic centimeters were required before the pink color of the erythrosin appeared. Look along the left-hand margin of the chart, below the zero line, and find 6 on the scale marked "$\frac{n}{50}$ Sodium Carbonate in CC." Follow this line horizontally toward the right until the diagonal line marked "H_2SO_4 Acidity with 1 cc. Erythrosin" is intersected. This occurs midway between two vertical lines. Following downward between these to the lower margin, this is intersected one-half space beyond the heavy vertical line marked 60. As each space on the lower margin corresponds to two parts per million, the result of the test, in parts per million, is 61.

Example No. 3. Test for Free CO_2 with Phenolphthalein. In making a test for free CO_2 in accordance with instructions on page 106, 7 cubic centimeters of reagent were used to produce a pink color. In the left-hand margin of the chart find 7 in the column marked "Reagent Required in Cubic Centimeters." Tracing to the right along the horizontal line through this point, until the diagonal marked "Free CO_2 with Phenolphthalein" is reached, follow downward along the vertical line through this intersection, and at the lower margin find 30.8 as the result in parts per million.

Example No. 4. Test for Free CO_2 in an Acid Water. Assuming that it is desired to test for free CO_2 a sample of water which has an acidity with erythrosin of 24 parts per million (requiring 2.4 cubic centimeters of $\frac{n}{50}$ Na_2CO_3 to neutralize). It is found to require 7.1 cubic centimeters of $\frac{n}{50}$ Na_2CO_3 to produce a pink color phenolphthalein. In the scale on the left-hand margin estimate the point corresponding to 7.1 (7 is the line midway between 6 and 8; 7.1 would be 1/20 of a space, a very small distance, above this). Follow this line horizontally toward the right until the "Free CO_2" diagonal is reached. This occurs about midway between two vertical lines. Follow downward between these until the horizontal line under "O" in the left-hand scale is reached. From this point continue downward and toward the left, parallel to the light diagonals until the horizontal line through 2.4 cc. on the "$\frac{n}{50}$ Sodium Carbonate" scale is reached. (This horizontal is the second line below "2" on this scale, as each space represents 0.2 cc. of reagent.) From this intersection follow vertically downward to the lower margin, where the result in parts per million is found to be 10.

Alkalimetry and Indicators. The tests for alkalinity and CO_2 involve the use of alkalimetry (or acidimetry) and indicators. The bases (as sodium hydroxid (NaOH) and calcium hydroxid ($Ca(OH)_2$) and certain salts cause alkaline reaction in water due to the presence of hydroxyl (OH') ions. The salts give this reaction by interaction with the water, a phenomenon known as *hydrolysis*. As an example of this interaction take a solution of sodium carbonate in water; the salt is ionized as $Na^{\cdot}$ and CO_3'', the water slightly as $H^{\cdot}$ and OH'. The two possible products are sodium hydroxid (NaOH) and carbonic acid (H_2CO_3). The latter is a weak acid—very slightly ionized—which does not affect the properties of the solution. The sodium hydroxid is ionized to a much greater extent, giving the water an alkaline reaction. This interaction may be represented schematically:

$$\left.\begin{array}{lll} Na_2CO_3 & \rightleftarrows 2Na^{\cdot} & + CO_3'' \\ 2H_2O & \rightleftarrows 2H^{\cdot} & + 2OH' \end{array}\right\} \rightleftarrows 2NaOH$$

Other salts, which by hydrolytic action with water produce a highly ionized acid, give the water an acid reaction. Thus the hydrolysis of aluminum sulphate is as follows:

$$\left.\begin{array}{l} Al_2(SO_4)_3 \rightleftarrows 2Al^{\cdot\cdot\cdot} + 3SO_4'' \\ 6H_2O \quad \rightleftarrows 6H^{\cdot} \ + 6OH' \end{array}\right\} \rightleftarrows 3H_2SO_4$$

The indicators used, phenolphthalein and erythrosin, have the faculty of indicating the presence of a small excess of either hydroxyl ions (OH') or hydrions (H) by changes of color. The phenolphthalein ($C_{14}H_{10}O_4$), a colorless substance and very feebly acid, is not perceptibly dissociated in solution:

$$C_{14}H_{10}O_4 \text{ (colorless)} \rightleftarrows C_{14}H_9O_4' \text{ (red)} + H^{\cdot}$$

In the presence of an alkaline salt the H ion combines with the OH' ion present and the above equilibrium is displaced forward, and a visible amount of the red negative ion is formed.

The action of these two indicators with substances commonly met with in the above tests is as follows:

Substance	Color with Erythrosin	Color with Phenolphthalein
Sulphuric acid, H_2SO	Colorless	Colorless
Ferrous sulphate, $FeSO_4$	Colorless	Colorless
Aluminum sulphate, $Al_2(SO_4)_3$	Colorless	Colorless
Carbonic acid, H_2CO_3	Not indicated	Colorless
Sodium bicarbonate, $NaHCO_3$	Pink	Not indicated
Calcium bicarbonate, $CaH_2(CO_3)_2$	Pink	Not indicated
Sodium carbonate, Na_2CO_3	Pink	Pink
Calcium carbonate, $CaCO_3$	Pink	Pink
Sodium hydroxid, NaOH	Pink	Pink
Calcium hydroxid, $Ca(OH)_2$	Pink	Pink
Sodium chlorid, NaCl	Not indicated	Not indicated
Sodium sulphate, Na_2SO_4	Not indicated	Not indicated
Calcium sulphate, $CaSO_4$	Not indicated	Not indicated

From this tabulation it is seen that phenolphthalein is a most delicate indicator with acids, indicating even carbonic acid. Its use in determining the acidity of a water would be confusing, as it would be affected by carbonic and weak organic acids present. Erythrosin indicates both sulphuric acid and the acid sulphates of aluminum and iron. If it is desired to determine the *free* sulphuric acid only, a less delicate indicator—methyl orange*—

* Methyl-orange indicator is made by dissolving 1/10 gram of the compound (also known as Orange III) in a few cubic centimeters of alcohol and diluting to 100 cc. with distilled water. The 100 cc. sample to be tested for acidity is titrated in the cold with sodium carbonate solution ($\frac{n}{50}$) using a few drops of methyl orange as an indicator. The methyl orange gives a red color with acid water, which changes to yellow when the acid is neutralized.

must be used instead of erythrosin and chloroform, in the test for acidity.

The table also shows that alkalinity may be due to the bicarbonates, carbonates, and hydroxids of the alkalies and alkaline earth metals. Bicarbonates in an untreated water are generally attributed to calcium (Ca) and magnesium (Mg), while carbonates are attributed to sodium (Na) and potassium (K), as the carbonates of these metals are soluble in water, whereas those of calcium and magnesium are only very sparingly soluble. If there is a sufficiency or surplus of carbonic acid present, all the alkalinity will exist as bicarbonates. Bicarbonates and hydroxids cannot exist together, as they react chemically, forming carbonates and water. It will be noted that erythrosin indicates all three kinds of alkalinity, whereas phenolphthalein indicates only carbonates and hydroxids. Another peculiarity of the alkalinity with phenolphthalein arises from the fact that it does not indicate bicarbonates. The reaction in neutralizing alkalinity with standard sulphuric acid may be represented by the equations:

$$CaCO_3 + H_2SO_4 = CaSO_4 + H_2CO_3$$
$$CaCO_3 + H_2CO_3 = CaH_2\,(CO_3)_2$$

Thus one unit of sulphuric acid neutralizes two units of carbonates as indicated by phenolphthalein. The following rules for determining the three types of alkalinity may be given:

1. When an alkaline water is neutral or acid with phenolphthalein the alkalinity is due to bicarbonates.

2. When the phenolphthalein alkalinity is less than half of the erythrosin alkalinity, twice the phenolphthalein alkalinity gives the carbonates, the difference between these and the erythrosin alkalinity gives the bicarbonates.

3. When the phenolphthalein alkalinity is one-half the erythrosin alkalinity, carbonates only are present.

4. When the phenolphthalein alkalinity is more than half the erythrosin alkalinity, hydroxids are present. To find the amount, multiply the difference between the two alkalinities by two and subtract this from the erythrosin alkalinity. The remaining alkalinity is due to carbonates.

5. When the phenolphthalein and erythrosin alkalinities are equal, only hydroxids are present.

Knowing the alkalinity of a water with phenolphthalein and

with erythrosin, the bicarbonates, carbonates, and hydroxids can be determined graphically from Plate II. The horizontal lines represent phenolphthalein alkalinity, as indicated by the scale on the left-hand margin, each space being equivalent to one part per million. The diagonal lines represent erythrosin alkalinity, each space being equivalent to 5 parts per million. The vertical lines represent the components of these alkalinities as bicarbonates (lower margin, toward the left), hydroxids (lower margin toward the right), and carbonates (upper right margin). The following examples will illustrate the use of this chart:

Example No. 1. Given a water of the following characteristics:

Phenolphthalein alkalinity — 25
Erythrosin alkalinity — 100

Find 25 on the scale along the left-hand margin (the heavy line midway between 20 and 30), and follow the line through this point horizontally to the right until the erythrosin diagonal marked 100 is reached. By following the vertical through this point downward to the lower margin, the *bicarbonate alkalinity* is found to be 50 (midway between 40 and 60). If the horizontal line through 25 is followed further to the right, it will be found to take a sharp upward turn, and continuing along this to the upper margin the *carbonate alkalinity* of the water is found to be 50 also.

Example No. 2. Given a water of the following characteristics:

Phenolphthalein alkalinity — 40
Erythrosin alkalinity — 60

Find 40 on the scale along the left-hand margin, and follow this line horizontally to the right until it intersects the erythrosin diagonal marked 60. Following the vertical line through this point downward to the lower margin, the water is found to have a *hydroxid* or *caustic alkalinity* of 20 parts per million. Following the heavy diagonal line through this same point of intersection upward to the upper margin, the *carbonate alkalinity* is found to be 40 parts per million.

The above determinations are in terms of *calcium carbonate.*

More properly they should be multiplied by the following factors:

Substance as $CaCO_3$	Multiply By	Gives Result As
Bicarbonates...	1.62	Calcium bicarbonate ($CaH_2(CO_3)_2$)
Carbonates....	1.06	Sodium carbonate (Na_2CO_3)
Hydroxids.....	0.74	Calcium hydroxid ($Ca(OH)_2$)

Sometimes it is desirable to determine the "half-bound" and "bound" carbonic acid (CO_2). To obtain these data, multiply the bicarbonates and carbonates respectively (in terms of calcium carbonate) by 0.44. It is not correct to record bicarbonates and half-bound CO_2, or carbonates and bound CO_2, in an analysis, as the one includes the other in both cases. Free CO_2, however, is an independent substance, as its name implies.

Iron. Apparatus: 1–100 cc. measuring glass; 1–250 cc. porcelain evaporating dish; 100 cc. Nessler tubes, 1⅛ inch diameter by 5¼ inches high to 100 cc. mark (at least twelve are required for permanent standards); 1–100 cc. burette, graduated to 1/10 cc. for standard iron solution.

Reagents: Hydrochloric acid (1:1); nitric acid (1:2); potassium permanganate solution (5 gm. per liter); potassium sulphocyanid solution (20 gm. per liter); standard iron solution ("dissolve 0.7 gram of crystallized ferrous ammonium sulphate in 50 cc. of distilled water and add 20 cc. of dilute sulphuric acid. Warm the solution slightly and add potassium permanganate until the iron is completely oxidized. Dilute the solution to one liter."* One cc. of this standard solution in 100 cc. of distilled water is equal to one part per million of iron).

Procedure: Boil 100 cc. of the sample several minutes in an evaporating dish with 5 cc. nitric acid. Add two or three drops of the potassium permanganate solution and allow to stand a few minutes. If the red color disappears, add more permanganate, drop by drop, until a faint pink color persists. Add 10 cc. of the potassium sulphocyanid solution, mix thoroughly, and pour into a 100 cc. Nessler tube. Pour 100 cc. of distilled water into a second Nessler tube, add 5 cc. of nitric acid and 10 cc. of potassium

* "Standard Methods of Water Analysis." American Public Health Association.

sulphocyanid. Add standard iron solution to the second Nessler tube until the color of its contents matches that of the sample. The number of cc. of iron standard added gives the dissolved iron in parts per million.

If the sample contains organic matter, it must be treated as follows: after filtering, evaporate to dryness and ignite to destroy

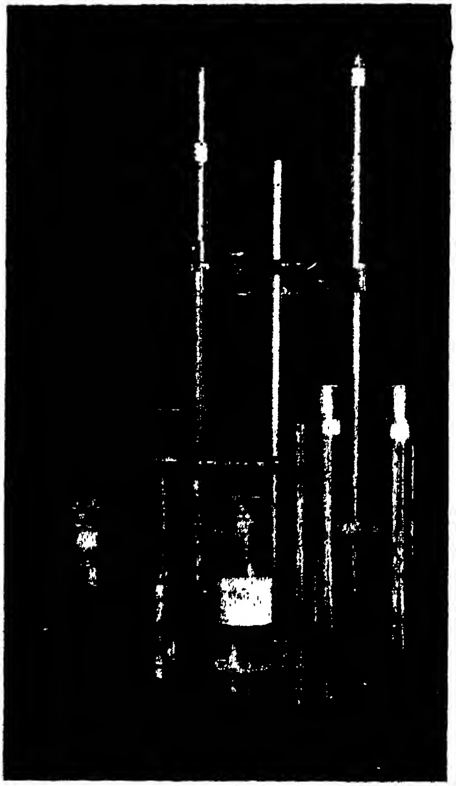


Fig. 64.—Apparatus for Iron Test.

organic matter; cool and add 5 cc. of hydrochloric acid (1:1) to residue, and if this is not dissolved immediately, heat gently; wash the liquid into a 100 cc. Nessler tube, and make up to 100 cc. with distilled water; then add potassium permanganate and sulphocyanid and proceed as before, using hydrochloric acid in the second Nessler tube also.

If desired, permanent iron standards, similar to the color standards herein before described, can be made up. The following solutions are required:*

Platinum solution: 12 grams of potassium platinic chlorid ($PtCl_4,2KCl$), dissolved in distilled water, with the addition of 100 cc. strong hydrochloric acid, and made up to one liter with distilled water.

Cobalt solution: 24 grams of cobaltous chlorid crystals ($CoCl_2,6H_2O$), dissolved in distilled water, with the addition of 100 cc. strong hydrochloric acid, and made up to one liter with distilled water. The standards are made up by the addition of various amounts of these solutions to distilled water in the 100 cc. Nessler tubes described under "Apparatus," as follows:

Standard Iron Solution, Parts per Million	No. of CC. Platinum Solution	No. of CC. Cobalt Solution	Standard Iron Solution, Parts per Million	No. of CC. Platinum Solution	No. of CC. Cobalt Solution
0.0	0	.0	1.5	28	17.0
0.1	2	1.0	2.0	35	24.0
0.3	6	3.0	2.5	39	32.0
0.5	10	5.0	3.0	40	43.0
0.7	14	7.5	3.5	40	55.0
1.0	20	11.0	4.0	40	67.0

In each case the platinum and cobalt solutions are poured into the Nessler tube first and enough distilled water is added to make up the solution to the 100 cc. mark. The water to be tested is treated as before, and after adding the potassium sulphocyanid is immediately compared with the permanent standards.

Logwood Test for Free Alum and Iron. Apparatus: Two 250 cc. porcelain dishes or casseroles.

Reagents: Solution of logwood in distilled water; acetic acid (glacial).

Procedure: Pour 100 cc. of water to be tested into each of two porcelain dishes. To the second dish add a small piece of alum or iron sulphate, and run this dish as a control, to check the color changes in the sample being tested. Add a few drops of logwood solution to each dish, stir gently, and observe the colors. Then add a few drops of acetic acid to each dish, stir, and note the

* Jackson, *Tech. Quar.*, 13, p. 320.

color changes. The colors obtained vary slightly with different waters, thence the need for running the check sample containing alum or iron along with the water being tested. Approximately the following color changes occur: If alum is present: when logwood is added, the water turns blue, when acetic acid is added the blue changes to red, fading gradually to yellow. If no alum is present: when logwood is added, the water turns red, when acetic acid is added, it changes to yellow. If iron is present: when logwood is added, the water turns a greenish black, when acetic acid is added the same color persists, changing gradually to yellow. If no iron is present, the color changes are the same as when no alum is present.

Test for Excess of Hypochlorite of Lime. Where a water is being sterilized with hypochlorite of lime, the following test may be used to indicate an excess in the treated water.* Fill a quart bottle with the treated water, add a small crystal of potassium iodid (K I), a few drops of weak acetic acid, and a teaspoonful of starch solution and shake thoroughly. A blue tint indicates an excess of hypochlorite, a violet tint shows that the amount being used is not excessive. The starch solution is made by boiling one part of starch in 200 of water for several minutes. Add a few drops of chloroform to preserve the solution. The bacterial test for sterility is most important, the above test being merely confirmatory and for use where facilities for bacterial work are absent.

Test for Strength of Hypochlorite Solutions. Place 10 cc. of the solution to be tested in a beaker or glass and slowly run in 1/10 alkaline arsenite solution,† stirring contents with a glass rod. At frequent intervals, a drop of the solution is removed on the glass rod and brought into contact with prepared starch paper.† Continue titration until no blue color is produced on the paper in this way. The cubic centimeters of arsenite solution used multiplied by 0.0355 gives the available chlorine in per cent.

* G. S. Woodhead, *Surveyor*, July 22, 1910.
† See Appendix B for preparation.

CHAPTER IV

BACTERIOLOGICAL TESTING OF WATER

THE bacteriological tests of water are of first importance in passing upon the safety and purity of a potable water, since the presence of a large number of bacteria in water is a certain indication of pollution and such pollution may include the "germs" of typhoid fever and other diseases, resulting in the production of these diseases amongst drinkers of the water so contaminated.

Because the routine of water bacteriology is apparently so simple, there is a great tendency to slight the details upon which success depends, and there is also an inclination upon the part of certain persons in authoritative positions to assert and recommend that the tests can be made with inexpensive apparatus supplemented by home-made makeshifts. But this can be done only by the use of an intimate skill and knowledge of detail which the amateur does not possess, besides wasting valuable time. Even with first-class apparatus, which in part compensates for the amateur's lack of knowledge and skill as to details, he will find plenty of pitfalls, and in addition the average filter-plant operator is not blessed with much leisure time to devote to this portion of his work. Therefore, the writer has not hesitated to specify all such apparatus as will be needed to properly and expeditiously perform the tests in question, carefully refraining from superfluities.

Especially to be kept in mind are:

1. *Accuracy* in all measurements, weighings, titrations, temperatures, etc.

2. *Sterility* of apparatus, remembering that bacteria are ubiquitous and many form spores which are able to resist slipshod attempts at sterilization.

3. *Contamination* of apparatus and material during operations, due to bacteria and dust from the air, from handling, etc., which can only be avoided by scrupulous care and a constant guard against all possible sources of such contamination.

While the instructions here given are quite full, it is always advisable for the beginner to obtain at least a few days' tuition under an experienced bacteriologist, as there are many small details which can be best imparted by personal instruction. It is further advisable to arrange for periodic visits by a waterworks' chemist and bacteriologist for the purpose of checking up methods, especially during the first year or so.

The Laboratory. This should preferably be a separate room, but force of circumstances may necessitate the use of a portion of a room intended primarily for other purposes, in which case it is desirable to enclose the portion so used by means of glazed partitions. It should be well lighted, and special effort should be made to obtain a northern exposure, because of the uniformity of light and absence of direct rays of the sun. It should not be exposed to dust, either chemical or ordinary, nor to fumes, such as chlorin gas, etc., even in minute quantities.

Uniformity in temperature is of course desirable and for reliability steam or hot-water heat is probably best.

As to furniture, a large, firm table is needed for plating, counting, etc., which should contain some drawers of ample size. There should be a cupboard, or shelves, for apparatus and chemicals, and a separate bench for the gas stove, etc. A large sink with running water and drainage is a necessity.

Schedules for Bacterial Tests. Three schedules for making bacterial tests will be given, in order to show just what tests should be made, and to furnish a definite basis for listing apparatus and equipment. In all cases daily tests should be made, and it will be assumed that glassware will be dry-sterilized weekly and that media is to be made up biweekly, where this part of the work is done.

Schedule A. This is for cases where all media is bought ready for use, as may be done to advantage in small plants, especially since it is now generally recognized that uniformity and reliability of results depend to a larger extent upon the care and accuracy with which the media are prepared than was formerly realized. Under this schedule only the daily plating, incubating and counting, and the weekly cleaning-up and sterilizing of glassware are to be done by the operator at the plant. The daily tests have been made as few and as simple as are consistent with obtaining the minimum data required for plant control.

Schedule A—Daily Tests

Operation	*Apparatus*
a. Sampling Raw and Filtered Water	2—Sample bottles
b. Plate Counts at 37°, 24 hours:	
1. Raw—plate 1 cc., 1/10 cc., 1/100 cc.	3—Tubes agar 3—Petri dishes 2—Dilution bottles 3—Pipettes—1 cc. 1—Pipette—10 cc.
2. Filtered—plate 2—1 cc. portions	2—Tubes agar 2—Petri dishes 1—Pipette—1 cc.
3. Control plate 1—1 cc. portion	1—Tube agar 1—Petri dish 1—Pipette—1 cc.
c. Fermentation at 37°, 24 hours:	
1 Raw — 1 cc., 1/10 cc., 1/100 cc.	3—Fermentation tubes Use same dilution bottles and pipettes as in *b* 1.
2. Filtered—10 cc., 1 cc.	1—Fermentation tube 1—Fermentation tube, 10 cc. 1—Pipette—10 cc.
3. Control—1 cc.	1—Fermentation tube

Schedule B. This contemplates the same tests as Schedule A, but embraces also the preparation of the media required, and therefore affects the apparatus lists hereafter given.

Schedule C. This is for a plant of moderate size, employing a technically trained man who combines the functions of plant superintendent with those of chemist and bacteriologist. It contemplates the preparation of all media required. It includes a 20° or "water-bacteria" count, and the use of litmus-lactose-agar, in place of plain agar, so as to give an additional check on the intestinal group of bacteria.

Schedule C—Daily Tests

Operation	*Apparatus*
a. Sampling Raw and Filtered Water	2—Sample bottles
b. Plate Counts at 20°, 48 hours:	
1. Raw—plate 1 cc., 1/10 cc., 1/100 cc.	3—Tubes gelatin 3—Petri dishes 2—Dilution bottles 3—Pipettes—1 cc. 1—Pipette—10 cc.
2. Filtered—plate 3—1 cc. portions	3—Tubes gelatin 3—Petri dishes 1—Pipette—1 cc.
c. Plate Counts at 37°, 24 hours:	
1. Raw—plate 1 cc., 1/10 cc., 1/100 cc.	3—Tubes lactose agar 1—Tube litmus solution 1—1 cc. pipette 3—Petri dishes Use same dilution bottles and pipettes as in *b* 1
2. Filtered—plate 3—1 cc. portions	3—Tubes lactose agar 3—Petri dishes Use same litmus and pipette as in *c* 1; use same pipette as in *b* 2
3. Control plate, 1—1 cc. portion	1—Tube agar 1—Petri dish 1—Pipette—1 cc.
d. Fermentation at 37°, 24 hours:	
1. Raw—1 cc., 1/10 cc., 1/100 cc.	3—Fermentation tubes Use same dilution bottles and pipettes as in *b* 1

2. Filtered—10 cc., 1 cc., 1/10 cc.	2—Fermentation tubes 1—Fermentation tube, 10 cc. 1—Pipette—10 cc. 1—Pipette—1 cc. 1—Dilution bottle
3. Control—1 cc.	1—Fermentation tube

Apparatus and Equipment. The following lists give all the apparatus required for these tests:

Bacteriological Apparatus Required

Schedule A (Assuming no media is to be prepared)

1—Incubator, 37° C., about 13″×13″×14″ high inside dimensions; two movable shelves.
1—Sterilizer, Hot Air, about 14″×24″×18″.
1—Ice Box, for storing media, about 2 cubic feet capacity.
1—Bunsen Burner (or alcohol burner).
1—Counting Apparatus, Wolfhuegel.
1—Lens, Tripod, for counting, 5X.
1—Pot, enameled, 4″ diam. × 4″ deep, for melting agar.
1—Tripod Support for above pot.
1—Thermometer, 0–100° C.
3—Tube Supports, for fermentation tubes, 10 tubes each.
24—Sample Bottles, wide mouth, glass stoppers, 250 cc.
60—Petri Dishes, 10 cm. diam., 1.5 cm. deep, porous covers.
60—1 cc. Pipettes, bacteriological.
24—10 cc. Pipettes, bacteriological.
2—Pipette Boxes, copper, 4″×4″×15″.
1—Jar, of stoneware, 8″ diam. × 12″ high, for cleaning solution.
1—Wash Boiler, for boiling old cultures.
1—Package Cotton Batting (non-absorbent).
12—Towels.
1—Lb. commercial sulphuric acid.
1—Lb. commercial potassium bichromate.
6—Wax glass pencils.

Schedule B (Assuming media is to be prepared) Requires in Addition to *Schedule A*

1—Autoclave, 11″ diam. × 24″ deep, with 2-shelf rack and 4-tube burner.

2—Enameled Pots, 3-quart capacity, for media.

1—Gas Stove, two-burner, or equivalent electric hot plate.

1—Balance, two-pan type, 1000 grams × 1/10 gram.

2—Burettes with glass stop-cocks, 25 cc. × 1/10 for $\frac{n}{20}$ sodium hydroxid and hydrochloric acid.

1—Burette Stand for two burettes.

6—Beakers, 350 cc. tall, with lip.

2—Funnels, ribbed glass, 6″ diam.

1—Funnel, plain glass, 4″, with rubber tube, pinch-cock, and glass tip, for tubing media.

48—Dilution Bottles, round, small-necked, 8-ounce.

1—Ream Agar Filter Paper.

2—Glass Spoons or Stirring Rods, 10 inches long.

3—Flasks, Erlenmyer, 1000 cc.

6—Flasks, Erlenmyer, 250 cc., hard glass, for media.

144—Test Tubes, bacteriological, ⅝″×6″, flint glass.

4—Wire Baskets, for test tubes, 6″×6″×5″deep.

6—Test Tube Brushes.

100—Fermentation Tubes, Dunham's, for 1 cc. samples, outer tubes 3″×⅜″, inner 6″×⅝″, hard glass.

20—Fermentation Tubes, Smith's, for 10 cc. samples, American Public Health Association Standard, large size.

2—5 cc. Pipettes.

1—100 cc. Graduated Cylinder.

1—4″ Evaporating Dish.

1—Lb. Agar, shredded and dried.

1—500-gram Bottle Peptone, Witte's, Armour's, Difco, or Fairchild.

1—4-ounce Jar Beef Extract, Liebig's.

1—Lb. Lactose, chemically pure.

1—Liter Normal Hydrochloric Acid, in glass-stoppered bottle.

1—Liter $\frac{n}{20}$ Hydrochloric Acid, in glass-stoppered bottle.

1—Liter Normal Sodium Hydroxid, in rubber-stoppered bottle.

1—Liter $\frac{n}{20}$ Sodium Hydroxid, in rubber-stoppered bottle.

1—Ounce Phenolphthalein Indicator.

2—Asbestos Hot Plates, for gas stove.
1—Gallon Distilled Water (to be bought as needed), or
1—Automatic Still, capacity, ½-gallon per hour.

Schedule C Requires in addition to *Schedule B*

1—Incubator, 20° C., 8½″×13″×8″ high, inside dimensions, ice-cooled.
144—Test Tubes, bacteriological, ⅝″×6″, flint glass.
2—Wire Baskets for test tubes, 6″×6″×5″ deep.
10—Fermentation Tubes, Dunham's for 1 cc. samples.
12—Dilution Bottles, round, small-necked, 8-ounce.
60—Petri Dishes, 10 cm. diam., 1.5 cm. deep, porous covers.
12—1 cc. Pipettes, bacteriological.
1—4-ounce bottle Litmus, c. p.
1—Lb. best French Gelatin.
1—Wire loop, No. 27 g, platinum, in glass handle.

The apparatus listed for Schedule A costs approximately $160; the additional apparatus for Schedule B costs approximately $150, or a total of $310; the additional apparatus for Schedule C costs approximately $90, or a total of $400. Estimates are based on 1919 prices.

Hot Air or Dry Sterilizer. This is used for sterilizing glassware. It consists of an oven of sheet metal or asbestos, with double walls, constructed so as to produce a uniform heat all around the inside of the oven by connected openings between the double-walled door and the sides. It should be provided with one or more wire shelves. A thermometer should be provided for noting the temperature of sterilization. A thermostat for

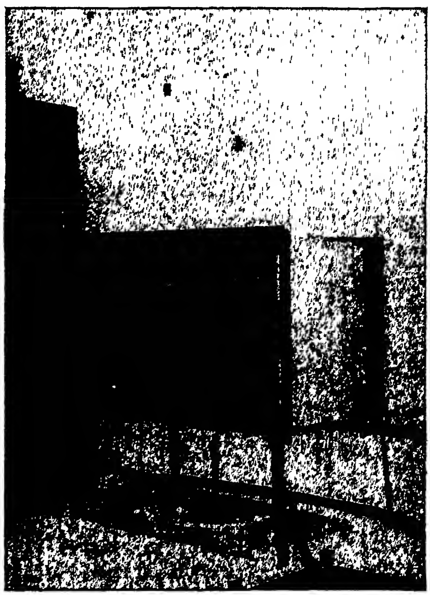


FIG. 65*a*.—Dry Sterilizer (closed).

controlling the temperature is desirable but not essential. A convenient size is 18 inches high, 24 inches wide, and 14 inches deep. Heating is accomplished by means of two Bunsen burners

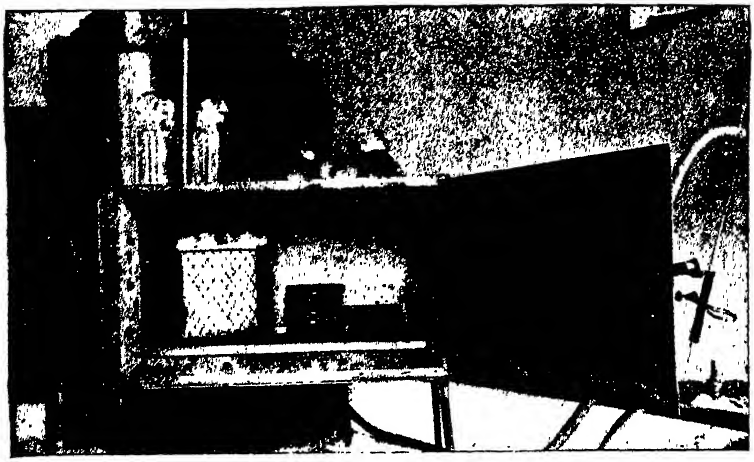


FIG. 65b.—Dry Sterilizer (open).

FIG. 66.—Steam Sterilizers.

or by built-in gas-jets or by setting the sterilizer over the gas stove. If gas is not available, good results can be accomplished by using a wickless oil heater of "Primus" type. Care should be taken to maintain a uniform temperature throughout the

chamber during sterilization, and to use a non-luminous flame, as otherwise the glassware will be covered with soot. The glassware should be allowed to cool in the sterilizer, as it is liable to crack if removed when hot.

The Autoclave. This is used for sterilizing agar, gelatin, broth, and dilution bottles, in fact, any liquid-containing substance which would be evaporated by dry sterilization. It operates under a slight steam pressure, and is therefore more rapid and effective than the open type of steam sterilizer, such as the Arnold. It consists of a strong cylinder of copper, tinned inside, or more recently of aluminum or steel plate, and is provided with a tight-fitting removable cover, fastened down with clamps. This cylinder is supported on a sheet-iron base, which encloses the heating element, usually a four-tube Bunsen burner, but in the absence of gas, an oil burner as above described may be used. The autoclave is provided with a pressure gage, a thermometer, a safety valve, and a pet-cock for the escape of air. In use the lower part of the cylinder is filled with water, the media is placed upon a rack, of one or more shelves, provided, and lowered into the cylinder, and the lid is clamped down. The air-cock is then opened and the burner placed under the autoclave. When steam begins to issue the air-cock is closed. The steam pressure is now allowed to build up to the point determined by the safety valve, usually fifteen pounds, and allowed to remain thereat for the required length of time. Then the burner is removed, and the pressure

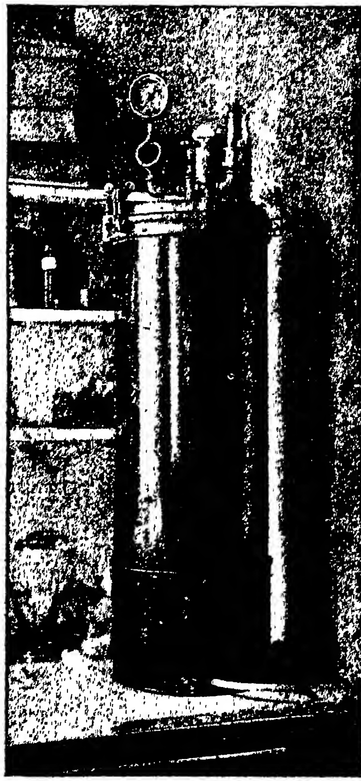


Fig. 67.—Autoclave.

is allowed to die down before opening the autoclave and removing the media, as otherwise the plugs will be blown from the tubes and flasks by the unequal pressure within them.

As soon as possible after sterilization the media must be removed and cooled rapidly. Media shall be sterilized in small containers, not over two inches in diameter.

The Arnold Sterilizer. This is used to sterilize liquid media at atmospheric pressure or at a temperature of 100° C. It was formerly used for all media containing sugars (lactose, dextrose, etc.), but more recently, with doubtful wisdom, it has been superseded by the autoclave. Where it is available it may advantageously be used for such media. It consists of a water-pan, surmounted by a metal box with double walls, forming an air space between. There is a double door on one side. The media is supported on perforated shelves. In operation a Bunsen burner is placed below the water-pan to generate steam, which streams upward through the perforated bottom and shelves, enveloping the media, and, passing through an opening in the inner surface of the double roof, is condensed against the outer surface and flows down between the double walls to the water-pan. Media must be subjected to the streaming steam for half an hour on three successive days before it can be considered sterilized.

FIG. 68a.—37° C. Incubator (closed).

The 37° Incubator. Two types of construction are used in

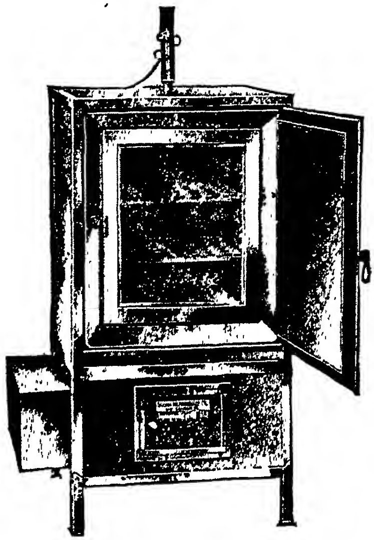
incubators. In one type a copper water-jacket forms three sides, top and bottom of the incubator, the fourth side being occupied by a double door, the inner of glass. This water-jacketed chamber is further surrounded by an insulating cover with an air space between, through which the heated air, which maintains the proper temperature within the incubator, circulates. In this type, the maintenance of a uniform temperature depends upon the heat storage capacity of the water surrounding the incubating chamber, and it would seem needless to say that the water-jacket should be kept full, were it not that occasionally such incubators are found in operation with the water-jacket only partially filled or even empty. In the second type, the walls are built of several plies of insulating materials, asbestos, felt, etc., no water-jacket being used, but the same arrangement of two doors, an inner one of glass, and an outer one of wood or metal, being maintained.


FIG. 68*b*.—37° C. Incubator (open).

The incubator may be heated by an oil lamp, by gas, or by electricity, using, in the last case, either heating coils or carbon lamps. A thermostat is provided, which automatically regulates the heating element so as to maintain a predetermined temperature in the incubator. A new incubator should be tested to see that the thermostat maintains a constant temperature and that the temperature in various parts of the chamber is uniform, at least to

within 1° C. Aside from an even temperature, the essential requirements in the incubating chamber are: darkness, good ventilation, and moisture, the last being obtained by having a pan of water always in the incubator. In addition, the incubator should be kept clean, inside and out, and free from odor.

The 20° Incubator. Everything said above applies equally to the 20° incubator. In warm weather it becomes necessary to



Courtesy Scientific Materials Company, Pittsburgh, Pa.

FIG. 68c.—Incubator (Water Jacketed, Electrically Controlled, Suitable for 20° C. Counts).

resort to artificial cooling to maintain the proper temperature. This is accomplished by circulating cold water from an ice coil through the water-jacket of the incubator, or else the incubator is provided with an ice-chamber and is cooled by cold air like an ice box. Unless proper provision is made in the first place, trouble is sure to result if makeshift methods of keeping down the temperature are attempted, and in such cases it may be better to circulate tap water through the water-jacket and keep a record of the temperature of incubation. During the cooler months of the year no trouble is met in maintaining the proper temperature, if the incubator is placed in an underheated room. The 20°

incubator is equipped with heating elements and thermostat just as is the 37° incubator.

Preparation of Media and Apparatus

Cleaning Apparatus. For cleaning new and used glassware (after boiling out) a stock solution of cleaning fluid should be prepared.

Cleaning Solution

2 liters of water, add:
100 cc. commercial sulphuric acid,
100 grams potassium bichromate,
Keep in a two-liter glass-stoppered bottle.

The stock solution is too strong for use, it being customary to add one part of it to seven of water, in the large stone jar provided. Flasks, test-tubes, fermentation-tubes, Petri dishes, and pipettes should be immersed in this solution and allowed to remain overnight. The solution should then be poured off and the glassware should be very thoroughly rinsed under the tap, and placed in the dry sterilizer for half an hour, to dry it. It is convenient to wear rubber gloves and apron when handling the cleaning solution.

Preparing Apparatus. After being cleaned as above, the apparatus should be prepared for use as follows:

The sampling bottles should be stoppered, and either wrapped separately in paper or have their stoppers and necks covered with tin-foil. A narrow strip of paper inserted under stopper will prevent sticking.

The flasks, test-tubes, fermentation-tubes, and dilution bottles (if not glass-stoppered) should be plugged with cotton batting, the cotton plug being large enough to completely fill the neck of the tube or flask for a distance of three-quarters inch, being seated with sufficient firmness to sustain the weight of the tube or flask, and with a tuft of cotton protruding for handling.

Petri dishes are closed in pairs, and then every 5 pairs (Schedule A and B) or 6 pairs (Schedule C) are wrapped in paper and tied, not to be opened until used.

Pipettes are placed in one of the copper cans, point down, and the cover put on.

All this apparatus is then sterilized in the dry sterilizer for two hours at 150° C., at which temperature the cotton plugs should brown slightly.

Preparing Media. *a. Nutrient Gelatin* (for 20° count):

1. Add 3.6 grams of beef extract and 6 grams of peptone to 1200 cc.* of distilled water and add 120 grams of gelatin (dried for one-half hour at 105° C. before weighing).

2. Heat slowly in an enameled pot until all the gelatin is dissolved, keeping the temperature below 65° C.

3. Make up to 1200 cc. and adjust the reaction as follows: Pour 45 cc. of distilled water (neutral to phenolphthalein) into an evaporating dish, and add 5 cc. of the gelatin with a pipette. Place the dish over a Bunsen burner and boil briskly for one minute (to remove CO_2), then add 1 cc. of phenolphthalein indicator, and titrate with $\frac{n}{20}$ sodium hydroxid until a faint, permanent pink color is produced, and note the reading. Twelve times this amount of the *normal* sodium hydroxid is required to render the gelatin neutral. Usually the gelatin will run from 0.5 to 1.5 per cent. acid, that is, the test will show that from 6 to 18 cc. of normal sodium hydroxid are required to render it neutral. Since the standard reaction is 1.0 per cent. acid, no correction need be made if the acidity lies within the above range. Should the test show more acidity, then add *normal* sodium hydroxid to the extent of 12 cc. less than 12 times the burette reading. Should the broth be neutral or slightly alkaline, titrate with $\frac{n}{20}$ hydrochloric acid and add *normal* hydrochloric acid to the extent of 12 cc. more than 12 times the burette reading. The addition of acid is unusual and indicates something to be at fault with the distilled water or the ingredients, since these themselves should contain organic acids. After correcting the titer of the gelatin, stir well to mix it thoroughly.

4. Filter through three layers of cotton flannel placed in the ribbed funnel, rough side up. The filters should be arranged as in Fig. 69. Place the wash-boiler containing about 1 inch of water on the two-burner gas stove. Place each of the flannel-lined funnels in a clean, one-quart Mason jar and cover with a por-

*The best way to determine these volumes is to place the empty pot on the coarse balance, and put sufficient weights on the other scale pan to balance it. Then add 1200 grams in weights, and pour the distilled water into the pot until it balances again.

celain dessert plate. Now put the filters and jars in the wash-boiler and allow them to steam for 10 minutes to warm up. Then pour half of the gelatin (which has been kept warm) into each

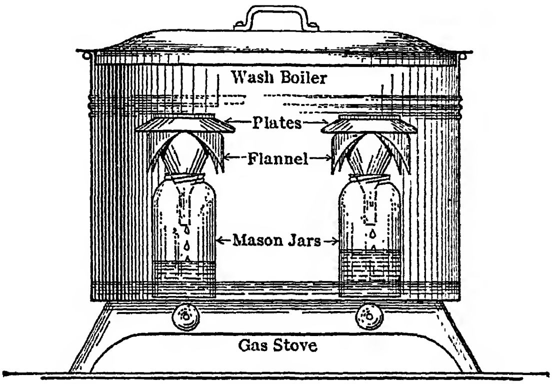


FIG. 69.

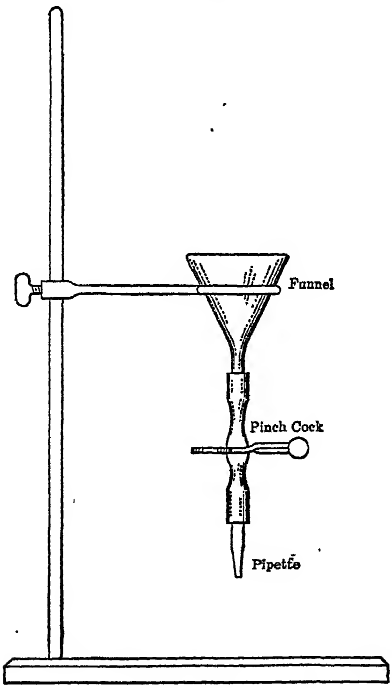


FIG. 69 *a*.

of the filters, replace the porcelain plates, and cover the wash-boiler. In from 5 to 10 minutes the gelatin will have all filtered through. Do not allow it to remain unnecessarily long. Agar filter paper may be used instead of cotton flannel.

5. Distribute into test-tubes, 10 cc. per tube, filling from 90 to 100 tubes (for two weeks' tests), putting any surplus into ster-

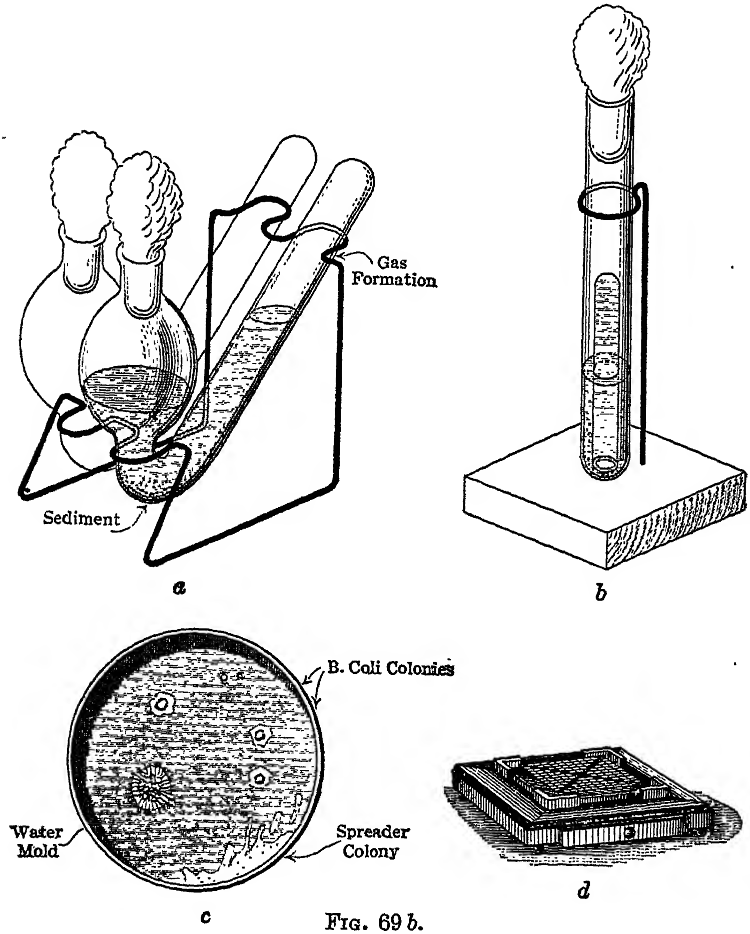


Fig. 69 *b*.

a. Smith Fermentation Tubes.
b. Dunham Fermentation Tube.
c. Plate showing Typical Colonies.
d. Wolfhuegel Counting Apparatus.

ilized Erlenmyer flasks. Use the device of Fig. 69*a* for tubing. Use all test-tubes of one size, as then 10 cc. of water can be put into one and the same height marked on all the others with a wax pencil.

6. Sterilize in the autoclave at 15 lbs. (120° C.) for 15 minutes after this pressure is reached. Remove immediately and set the tubes in a pan of water to chill. Store in ice box which contains a pan of water to keep atmosphere moist. *Do not use any media over two weeks old.*

*b. Nutrient Agar** (for 37° count):

1. Add 3.6 grams of beef extract, 6 grams of peptone, and 15 grams of agar (dried for one-half hour at 105° C. before weighing) to 1200 cc. of distilled water. Boil in an enameled pot until dissolved, then make up the loss through evaporation, by adding sufficient distilled water to bring the volume up to 1200 cc.

2. Titrate a 5-cc. sample, as directed for gelatin, and if the reaction is not already between 0.5 and 1.5 per cent. acid, adjust as directed for gelatin.

3. Cool to 45° C. by setting pot in cold water, then warm until melted, without stirring.

4. Filter as directed for gelatin.

5. Distribute in test-tubes, 10 cc. to each tube, putting any surplus in Erlenmyer flasks. (Required, 90 tubes.)

6. Sterilize in the autoclave at 15 lbs. (120° C.) for 15 minutes after the pressure reaches 15 lbs. Store in ice box in moist atmosphere.

*c. Lactose Agar** (for 37° count and acid-forming bacteria):

1. Carry out the first step as directed under *b* 1. (Nutrient Agar.)

2. Titrate and adjust the reaction to *neutral* by adding normal sodium hydroxid to the extent of 12 times the burette reading.

3. Cool and warm as under *b* 3.

4. Filter as before, and pour 1000 grams into a clean pot, discarding any surplus.

5. Bring to boiling-point, remove from flame, and add 10 grams of lactose, stirring thoroughly until dissolved.

---

*Read over directions for gelatin if not already done.

6. Distribute in test-tubes, 10 cc. per tube. (Required, 90 tubes.)

7. Sterilize in the autoclave at 15 lbs. (120° C.) for 15 minutes after the pressure reaches 15 lbs. Have the autoclave thoroughly heated, with the water at boiling-point before introducing the media.

d. Litmus Solution (for lactose agar plates):

1. Add 2 grams of Merck's pure reagent litmus (previously powdered) to 100 cc. of distilled water, and boil for 5 minutes.

2. Distribute into cotton-plugged, sterilized test-tubes, 7 cc. per tube. (Required 15 tubes.)

3. Sterilize in the autoclave for 5 minutes at 15 lbs. (120° C.)

e. Lactose Broth * (for Coli test in fermentation tubes):

1. Add 6 grams of beef extract and 10 grams of peptone to 2000 cc. of distilled water.

2. Heat slowly in a 3-quart pot until dissolved, reaching a temperature of at least 65° C.

3. Make up lost weight, titrate a 5-cc. sample, and adjust the reaction to *neutral* by adding normal sodium hydroxid to the extent of 20 times the burette reading.

4. Cool to 25° C. and filter through agar filter paper.

5. Bring to boiling-point, remove from flame, and add 20 grams of lactose, stirring thoroughly until dissolved.

6. Distribute into fermentation-tubes as follows:

   a. 80 *Dunham tubes,* cotton-plugged and sterilized. Fill each tube about half full, allowing the inner tube to float on top of the broth, open end down. It is important to fill Dunham tubes with broth boiling hot, and to sterilize at once, otherwise air-bubbles may appear in the inner tubes.

   b. 16 *Smith tubes, large size.* Fill the closed arm completely, but only have enough broth in the bowl to form an effective seal.

f. Dilution Bottles.

With the graduated cylinder, measure 101 cc. of distilled water into each of 16 sterilized dilution bottles, and 90 cc. of

* Read over directions for gelatin if not already done.

distilled water into each of 32 sterilized dilution bottles, reinsert the cotton plugs, and sterilize in the autoclave for 15 minutes at 15 lbs. (120° C.). This is for Schedule C; for Schedule B only 16 of the 90 cc. dilutions are needed, for two weeks' tests.

(If test-tubes are used instead of dilution bottles, measure out 9 cc. of distilled water per tube, which should be plugged

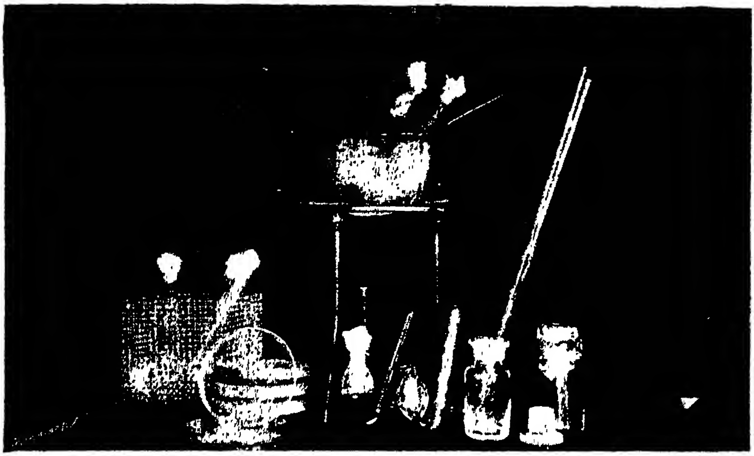


Fig. 70.—Apparatus for Bacterial Tests.

Note tubes of sterile distilled water in basket, agar tubes warming in water bath, sterile Petri dishes (those behind have porous earthenware covers), fermentation tubes, sterile pipettes, and sample collecting bottles.

and sterilized as for media. In this case Schedule C will require 64 tubes and Schedule B, 48 tubes. Dilution bottles are preferable.)

Testing Media. At least three tubes of each fresh batch of media, whether agar, gelatin, or broth should be tested. This is most conveniently done by making a duplicate test of the raw water on both the new and the old media and comparing results, which should be approximately the same as regards number of colonies, vigor of growth, etc.

Collecting Samples. Great care is necessary in collecting samples to get representative ones and to prevent contamination. Raw water samples must, of course, be taken before any chemical has been added. Usually the filtered water sample is taken from the discharge main, that is, after chlorination, if such is used. It

is well to take the samples from water mains or pipes rather than from basins or tanks, since the mixing action incident to flow through pipes insures a representative sample, which is not the case in quiescent water of basins or tanks. Therefore, it is recommended that the raw water sample be taken either from the low-service pump suction or discharge, and the filtered water sample from the high-service discharge main just as it leaves the pumping station. In each case these should be tapped by ½-inch pipes provided with full-size bib cocks, and these should be allowed to run full open for 10 minutes before taking the samples. In removing the tin-foil or paper and opening the bottle,

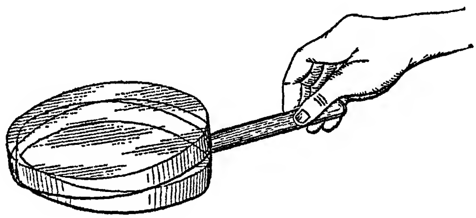


Fig. 71.—Plating Gelatin or Agar.

avoid touching the rim or mouth of same. While filling the bottle hold the glass stopper by the top, carefully out of contact with anything. In filling the bottle and replacing the stopper the water must not be allowed to run from the fingers upon the stopper or into the mouth of the bottle. Samples from basins, tanks, rivers, etc., are generally taken about a foot below the surface, the bottle pointing against the current, or in quiescent water with a sweeping motion. For routine analyses fill the bottle only half full, but where storage or transportation are necessary, fill it completely, leaving a small air space only for expansion. Routine samples should be plated at once. Where transportation or storage is necessary the period should not exceed 6 hours for impure water or 12 hours for pure water, and during storage the temperature shall be kept as near 10° C. as possible. A note shall be made of the time and conditions of storage.

Plating on Gelatin and Agar (for bacterial counts). (The procedure is described for Schedule C, which is the most complete, and the reader can easily make the necessary omissions for Schedules A and B).

An hour before collecting the samples place 6 small and 1 large fermentation-tube in the autoclave or Arnold and heat to drive off dissolved gases. Then after seeing that there are no gas-bubbles in the tube, place them in the 37° incubator to temper until ready to be inoculated.

Place 8 tubes of lactose agar (plain agar for Schedule A and B), and 7 tubes of gelatin (omitted in A and B) vertically in the small melting pot, and add water sufficient to submerge the media in the tubes. Place pot on tripod over the Bunsen burner and heat to about 65° until the media is entirely melted. Then allow to cool and maintain at about 45° C. until used. Keep a thermometer in the pot.

Set out 13 sterilized Petri dishes and mark them all with a wax pencil with date, six "Raw," six "Filt.," three each of Raw and Filt. "20°" and the remainder "37°," mark the last one "Control." Then mark one each of the 20° and 37° Raw, "1," "1/10," "1/100." The "Filt." are all for 1 cc. samples.

Set out also one 101 cc. dilution bottle, marking same "1/100 R.," and one 90 cc. dilution bottle, marking it "1/10 R.," and one 90 cc. dilution bottle for the filtered marked "1/10 F." Also place handily the can of sterilized pipettes and the empty can in which the used pipettes are to be placed immediately.

Remove the fermentation-tubes from the incubator, setting three with the group of dishes and dilution bottles for the raw water, and three with the filtered group, marking them "R. 1/100," "R. 1/10," "R. 1," and "F. 1/10," "F. 1," and "F. 10" (the large one), respectively, and one "Control," together with date.

Flame the mouth of the "1/100 R." dilution bottle, remove the stopper, holding same between the second and third finger of the left hand by the tuft, and refraining from touching it to anything. Take a sterile 1 cc. pipette and, immersing the tip slightly below the surface of the dilution water, draw off 1 cc., and introduce it into the Petri dish marked "Control." Similarly introduce a second pipetteful into the fermentation-tube marked "Control" and discard the pipette.

Now take the raw sample and, after shaking vigorously at least 25 times with a stroke of 12 inches, remove stopper carefully, and with a sterile 1 cc. pipette introduce 1 cc. of the sample into each of the two Petri dishes marked, "Raw. 1", raising the

covers only far enough to admit the point of the pipette, and also, with the same pipette, introduce 1 cc. of the sample into the "1/100 R." dilution bottle and into the R1 fermentation-tube (replacing cotton stoppers*). Do not immerse the tip of the pipette in the liquors inoculated and do not blow *through* it. Now discard this pipette and place it in the empty can. Now with a sterile 10 cc. pipette introduce 10 cc. of the sample into the "1/10 R." dilution bottle.

Next take up the "1/100 R." dilution bottle and shake it vigorously 25 times. Then, using a sterile 1 cc. pipette, introduce 1 cc. of the dilution into each of the two Petri dishes marked "Raw, 1/100" and into the fermentation-tube marked "R. 1/100." Discard the pipette.

Then, take up the "1/10 R." dilution bottle and shake it vigorously 25 times. Using a sterile 1 cc. pipette, introduce 1 cc. of the dilution into each of the two Petri dishes marked "Raw 1/10" and into the fermentation-tube marked "R 1/10" with the usual precautions.

Remove one of the gelatin tubes from the water bath, allow it to cool slightly, then pass the cotton plug through the Bunsen flame, and remove it. Flame the mouth of the tube and pour the gelatin into one of the 20° Petri dishes, just raising the cover far enough to admit the mouth of the tube. Then immediately tilt the dish slightly back and forth so as to give the contents a rotating motion, which will mix the water sample and gelatin and spread the mixture evenly over the surface of the dish. Set the dish on a level surface to cool and harden. Proceed similarly with the other 20° Petri dishes.

To each of the 37° Petri dishes add 1 cc. of sterile litmus solution, using a sterilized pipette. Then add to each dish the contents of an agar tube (see that temperature is not over 45°) flaming the mouth of the tube as before, spread the agar evenly over the dish, and allow it to harden as before.

Now mix sample and broth in each of the fermentation-tubes, if of the Dunham type, by smartly tapping the side of the tube several times, if of the Smith type, by tilting forward so that all

*The mouth of dilution bottle and fermentation-tube must be held in the Bunsen flame before removing stopper, and stopper must be carefully held by the tuft, without contact with anything until replaced, previous to which it should again be passed through the flame.

the broth in the closed leg runs into the bowl, and then tilting backward so that the closed leg is completely filled again.

Incubation. Put the gelatin plates into the 20° C. incubator and incubate for 48 hours. Put the agar plates into the 37° C. incubator and incubate for 24 hours. If glass-covered Petri dishes should be used, invert them to prevent liquefaction. Put the fermentation-tubes into the 37° C. incubator, also. At the end

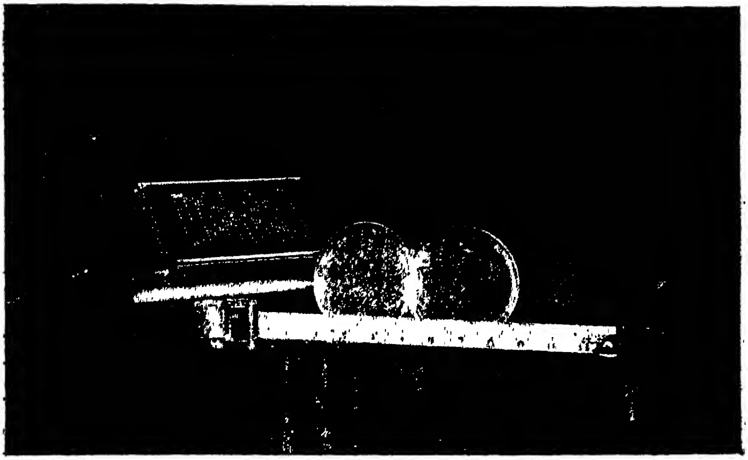


FIG. 72.—Plates from Incubator Ready to Be Counted.

Each spot on the plate is a colony, developed presumably from one bacterium. The left-hand plate is from a sample of polluted river water. The right-hand plate is the same water after filtration. The board and lens are used to facilitate counting.

of 24 hours examine the fermentation-tubes for gas formation and make a record of the finding for each tube, as either:

a. Gas absent.

b. Gas less than 10 per cent. of closed arm of tube.

c. Gas more than 10 per cent. of closed arm of tube.

Remove the fermentation-tubes after 48 hours' incubation and examine each tube again, recording the findings as was done after 24 hours' incubation.

Counting and Examination. After removing the gelatin plates count the colonies which have developed. Invert the Petri dishes and place them on the black plate of the counting apparatus and place the ruled counting plate on top, graduated side down.

Then count all of the colonies, using the tripod lens, unless there are over 400, in which case discard the plate. Also discard plates containing only a few colonies. About 200 colonies per plate give the most accurate count. If the plate chosen is one of the dilutions, say 1/10 cc., then the count must be multiplied by 10 to give the number of bacteria per cc.; if 1/100 cc., then multiply by 100. Study the shape and characteristics of the colonies and try to associate them with river stage, seasonal conditions, operating difficulties, etc. Many typical forms will soon become familiar and will indicate certain conditions affecting plant operation just as significantly as the turbidity and chemical tests.

Count the agar plates in the same manner, recording separately the total counts and the red colonies.

Fermentation Tests. The purpose of the fermentation-tube tests is to determine the presence of the Coli group of bacteria, which are indicative of pollution. It is called a presumptive test since it presumes that if gas is formed, B. coli are present, which is generally but not always the case.

a. If more than 10 per cent. gas is formed in 24 hours or less, then the test is considered as *positive presumptive*, and is indicated on the record by a + in the column for the quantity tested.

b. If none or less than 10 per cent. gas is formed in 24 hours, but gas is present in 48 hours, even in small amount, then the result of the test is *doubtful*, and requires confirmation before an entry can be made in the record.

c. If gas is *entirely absent* at the end of 48 hours, then the test is considered as *negative*, and is indicated on the record by a — in the column for the quantity tested.

In the case of *doubtful* tests, with the platinum loop (after first heating to redness in the Bunsen flame and allowing to cool), take a loopful of the sediment in the bottom of the fermentation-tube and streak this on a litmus-lactose-agar plate which has previously been poured and allowed to harden thoroughly.

If typical colonlike red colonies have developed after incubation at 37° C. for 24 hours, the test can be recorded as *positive*. If no red colonies appear in 24 hours, return plates to the incubator for another 24 hours. If no typical colonies have then appeared, record the test as doubtful by means of a question-mark, as only by a complete examination can a conclusive result be reached in such a case.

Control Tests. The control plate and fermentation-tube should be observed after the usual incubation period. These should show no bacterial growths, and if they do, it indicates that the apparatus and media used were not sterile, or that the methods were defective. A record of the control tests should be kept.

Boiling Out Old Cultures. Petri dishes, fermentation-tubes, test-tubes, etc., should be boiled for one hour in the wash-boiler provided therefor, in order to destroy the old cultures and dissolve the media. They should then be thoroughly rinsed and cleaned in hot water containing a little soda, but without soap. They are then ready to be placed in the cleaning fluid as previously described.

CHAPTER V

INTERPRETATION OF TESTS

Taste and Odor. Tastes and odors are often caused by the presence of diatoms, algæ, or small animalcules in the water. These tastes and odors are due to volatile oils given off by the cells of these growths. A very small amount of these oils causes a very appreciable taste, one part in ten million being often detectable. Certain odors seem to occur at stated seasons, some in spring and autumn, some in summer, others in midwinter, due to the formation of minute plant growths beneath the ice. Ground- and filtered-water supplies when stored in reservoirs seem to be especially favorable to the growth of algæ, probably owing to the relatively large amount of free carbonic acid which these waters contain. Covering the reservoirs is an effective, although expensive, remedy. Treating the water with copper sulphate is also good, one part of copper sulphate to 2,000,000 of water destroying lower plant and animal life in from two to four days. The proper amount of copper sulphate is placed in a gunny sack and dragged back and forth through the water until it is dissolved. Aerators at the inlet to the basin, and the chemical treatment of the water at the filter plant so as to prevent the increase in CO_2, also help.

Dissolved gases such as hydrogen sulphid (H_2S) and marsh gas (CH_4) cause disagreeable odors which can be removed by aeration. Odors often result from decomposing organic matter, especially when the gases due to decomposition are confined under ice in winter.

Most of the above tastes and odors can be removed by aeration, followed by sedimentation and filtration, although swamp waters sometimes have tastes which cannot be wholly removed.

Certain minerals cause tastes. Small amounts of oxygen, carbonic acid, salt, etc., give water a pleasant taste; their absence is noted in the " dead " taste of artificially distilled water. Salt in excess of 250 parts per million of chlorine, causes a distinctly briny taste. Iron is noticeable when it exceeds two parts per

million, and a high content of carbonates of lime and magnesium imparts a distinct flavor and an apparent "heaviness" to the water.

Hypochlorite of lime, when used for sterilizing water, imparts to it a taste and odor, especially when more than 6 to 8 pounds per million gallons are used. It is especially noted in hot water a fact which is true of most tastes and odors.

Turbidity. Turbidity is caused by the sediment which the surface runoff washes from the land and which is carried in suspension in the stream or river. Naturally it is highest during a flood, and an observer acquainted with the geology of a river basin can tell from the color and appearance of the turbidity in what part of the basin the rainfall causing the flood occurred. The turbidity is composed of fine particles of silica or sand and of clay. It is expressed most conveniently as parts per million of silica, although this does not express correctly the amount of suspended matter. The ratio, $\frac{\text{Suspended matter}}{\text{Turbity}}$, is called the "Turbidity Coefficient," which generally runs from 0.4 to 0.6, but increases with coarse sediment and decreases with fine. In alkaline waters (those containing carbonates or hydroxids of sodium and potassuim) silica and alumina often occur in a minutely divided or colloidal state, giving the water a smoky appearance, a form of turbidity very difficult to remove.

Turbidity is very significant in indicating the amount of chemical required for coagulation, as shown by Plates III and VI.

Filtered water should show no turbidity whatever, and in any drinking water a turbidity of 5 or over will cause unfavorable comment.

Color. Color is due to vegetable tannates and gallates, resulting from infusions of the leaves and bark of decaying vegetation, or to iron carried in solution in the form of acid carbonates and sulphates, often combined with organic matter. Swamp water is highly colored, due to the presence of decaying vegetation, peat and muck, and the prolonged contact of these with the water.

Waters containing turbidity due to clay generally have very low color, after the turbidity is removed, as the clay present in the colloidal state has the power of removing coloring matter from the water by a process known as "adsorption." For this

reason the turbid waters of the Mississippi Valley are practically colorless, while the clear mountain streams of New England are often very high in color.

Acid waters of swampy origin often have a black tinge, as the acids in combination with the tannates and gallates present form a natural ink. Iron sulphate gives to water a yellow cast, and waters containing iron carbonates held in solution by CO_2 acquire a very fine yellow turbidity when the CO_2 escapes, which is very persistent.

Color is undesirable, owing to the unpleasant appearance it gives a water, and to the fact that it stains linen and vegetables, and, in the case of iron, enamel ware and glass. Often irregularity in the behavior of coagulants, or the failure of coagulation, has been noticed with high color, but the reason is not yet well understood.* The maximum color in a filtered water should be less than 10 parts per million. The color will be found to decrease during floods, owing to the greater dilution of the water, but it sometimes happens that a river has a swampy tributary, a flood on whose basin will flush out the swamps and cause a temporary rise in color.

To remove color, the best results are obtained by coagulation with alum, and filtration. It requires about 1 grain per gallon of alum to effect a color reduction of 10 parts per million, but there seems to be a residuum which is very difficult to remove, requiring 3 or 4 grains for each 10 parts of color. The portion so difficult to remove is probably in true solution, the other being present as a colloidal solution.

Alkalinity. Alkalinity is the property of a water due to the presence of hydroxyl ions. It is caused by the hydroxids and carbonates of the alkalis (sodium and potassium), and by the hydroxids, carbonates, and bicarbonates of the alkaline earths (calcium, magnesium, and [occasionally] lithium). Of these the hydroxids of calcium and magnesium are found only in filter effluents (through improper operation), and the hydroxids of sodium and potassium in waters of the Far West. Carbonates of soda are common in many waters, and bicarbonates of calcium and magnesium are almost universally present and in the majority of waters con-

* It is thought that the coloring matter forms films about the minute particles of incipient coagulum and prevents these from collecting into sizable clots.

stitute at least fifty per cent of the mineral matter in solution. Calcium and magnesium carbonates are only slightly soluble, and are therefore found in small quantities only. If carbonic acid is present it combines with the carbonates to form the highly soluble bicarbonates of calcium and magnesium.

It is a common mistake to assume that alkalinity and "hardness" are the same, for this can only be true when all the alkalinity is due to bicarbonates of calcium and magnesium. These constitute "temporary hardness," so called from the fact that they are precipitated by heating the water, as the carbonic acid holding them in solution is then driven off. The sulphates, chlorids, and nitrates of calcium and magnesium do not contribute to the alkalinity of a water, yet they cause "permanent hardness," not being precipitated by ordinary boiling, although if boiled under pressure, as in generating steam for power purposes, they precipitate and form a hard scale in the boiler. Mineral acids also cause hardness.

Popularly any water with which it is difficult to obtain a soap lather is termed "hard." This difficulty arises from the fact that the salts of calcium and magnesium (and, to a small extent, of iron, lithium, and zinc) form insoluble salts with soaps, which form a scum on the sides of the containing vessel, and until the calcium and magnesium salts are thus precipitated no lather results. Taking sodium stearate ($NaC_{18}H_{35}O_2$) as a type of soap, the reactions are as follows:

For temporary hardness: $CaCO_3+2NaC_{18}H_{35}O_2=Ca(C_{18}H_{35}O_2)_2+Na_2CO_3$

For permanent hardness: $CaSO_4+2NaC_{18}H_{35}O_2=Ca(C_{18}H_{35}O_2)_2+Na_2SO_4$

Alkalinity finds a practical use in water purification by its reaction with alum (aluminum sulphate) to form a coagulant, as is more fully explained in Chapter VI, and diagrammed on Plates IV and V.

Potable waters should be alkaline at all times to the extent of at least 10 parts per million, and a maximum alkalinity of not over 75 is desirable in water supplies, to limit the soap consuming powers. For boiler-feed purposes an alkalinity of 100 or less gives very little trouble because of soft scale.

Acidity. This test as usually run with erythrosin indicates the acidity due to free sulphuric acid and the sulphates of iron and aluminum. By using methyl orange as an indicator, sulphuric acid *only* is indicated. The correction of acidity with lime and soda ash is shown on Plates IV and V, and explained in Chapter VI. Acid waters attack plumbing fixtures, piping, boilers, and even the cast-iron impellers of centrifugal pumps and the interior passages of plunger pumps. Ferrous sulphate, in particular, attacks wrought iron vigorously. Acid waters will destroy pathogenic bacteria such as B. coli, B. typhosus, and vegetative forms, and such waters often seem quite sterile. Many bacteria, however, form " spores " under adverse conditions and become active again after the water is rendered alkaline by the lime or soda ash used in coagulation, often to the surprise of the operator, the raw-water counts being zero and the settled-water counts very high.

Free CO_2. Carbonic acid is acquired by water in its passage through the air and over and through the surface soil, being a product of the decay and fermentation of vegetable and animal matter. It is generally present during, or increased by, a rising river, due to bayous, swamps, etc., containing stagnant water and decaying vegetation, being flushed out. The indication of other acids by this test and the correction to be made for such conditions have been pointed out.

The faculty of CO_2 for rendering the almost insoluble carbonates of calcium, magnesium, and iron soluble by entering into combination with them has been remarked. The combination does not seem to be a truly chemical one, as the CO_2 is readily driven off and the normal carbonates precipitated, in the case of calcium and magnesium, by heating, and, in the case of iron carbonates, by merely agitating or aerating the water. These bicarbonates are therefore generally indicated by chemical formulas as follows: $CaCO_3, H_2CO_3$; $MgCO_3, H_2CO_3$; and $FeCO_3, H_2CO_3$, the commas indicating a loose or temporary type of combination.

The presence of free carbonic acid renders a water more favorable to the growth of algæ and vegetable forms, it being an important source of food supply for plants.

In iron-lime coagulation, the CO_2 must be removed either by the addition of sufficiently more lime (above that required to react with the iron sulphate), or by aeration. The latter is generally the cheaper, but to be effective the contact of the air with the

water must be intimate. Water falling in thin sheets is not very effectively aerated, but by making it fall over successive steps, being broken into drops at each step, due to the splashing, it is possible to remove dissolved gases at the rate of 10 parts per million per second of exposure in summer, and about half that amount in winter. Where aerators are used, free CO_2 determinations should be made before and after aeration to determine the reduction, and the amount of lime used should be such as to remove the free CO_2 left after aeration.

Aside from its effect on the process of coagulation, free CO_2 has a very decided corrosive action on service pipes. This corrosive action is much more pronounced in the case of soft water than of hard, as the latter forms a protective coating of calcium carbonate on the inside surface of the pipe. For this reason a small amount of CO_2 (5 parts per million or less) is sometimes allowable in a hard water, not subject to marked decreases in alkalinity during floods, if it can be proven that there is no corrosive action on pipes. Lead pipe is most easily dissolved, and as the lead remains in solution in the water and is a cumulative poison, the use of a water, rendered corrosive by CO_2, is dangerous in such a pipe, ½ part per million of lead being considered the danger limit. Free CO_2 also dissolves and holds in solution zinc from the coating of galvanized pipe, this being injurious to health, but not so dangerous as lead, zinc not being cumulative (*i.e.*, not remaining in the system). Copper is also dissolved from brass pipe and is often a source of complaint, as when soap is added to the water (especially if it is very clear) a blue tinge results, owing to the reaction between the copper and the ammonia in the soap.

Water after treatment is free from carbonic acid if it reacts pink with phenolphthalein on addition of a drop of $\frac{n}{50}$ sodium carbonate. The proper amounts of soda and lime to use in removing carbonic acid is taken up in connection with coagulation (Chapter VI), and is shown on the diagrams, Plates IV, V, and VII.

Iron. Iron is present in water in the form of carbonate, ferric sulphate, and ferrous sulphate. Most sands, gravels, and rocks contain iron in the form of the oxid (Fe_2O_3). Water containing organic matter, coming in contact with this iron oxid in its passage through the ground, deprives it of oxygen, in order to oxidize the organic matter it contains, reducing the ferric oxid (Fe_2O_3) to ferrous oxid (FeO). The latter is combined with the carbonic acid

present in the water to form ferrous bicarbonate, which is carried in solution. Wells drilled near a polluted river are generally high in ferrous carbonates, and ground water supplies from subterranean gravel deposits may or may not be high in iron. The amount of iron in a water fluctuates, but if once present is not likely to decrease with consumption. Iron-containing waters are often clear when first pumped from the ground, but on standing a brown turbidity appears, as the water absorbs oxygen from the air, and as the carbonic acid in the water escapes.

Waters containing more than 0.5 part per million of iron are objectionable for domestic use, owing to the astringent taste, the discoloring of linen and porcelain, and the deposits of iron oxid in the mains, as the soluble carbonate oxidizes, which deposits appear at the faucets whenever the water in the mains is stirred up (as during a fire). A fungus, *Crenothrix polyspora*, grows in iron-containing waters, using the soluble iron in its life processes. As this organism requires no light, it will grow in the water mains, causing a disagreeable taste and odor, and, after its death, the sheath remains in the water as a brown, gelatinous precipitate.

Iron sulphate, both ferrous and ferric, is often present in water containing coal-mine drainage, and when held in solution by, or combined with, carbonic or organic acids, or with colloidal matter is most difficult to remove. It is present if the water tested shows iron and mineral acidity with erythrosin. Practically 1 part per million of iron combines with 3 parts of mineral acidity as H_2SO_4 to give 4 parts per million ferric sulphate. The amount of mineral acidity used in this way cannot be greater than the difference between the acidity with erythrosin and with methyl orange, and is less if aluminum sulphate is present. Iron sulphate has a practical use in coagulation, as the addition of lime causes coagulation to take place. This will be further taken up in Chapter VI.

Aeration is very valuable in removing soluble iron from ground water and should be followed by sedimentation and filtration to remove the precipitated oxid. Sometimes a satisfactory removal cannot be accomplished in this way, and the use of lime and alum must be resorted to.

The sulphate in mine waters is generally in both ferrous and ferric form, but if the water is high in organic matter or for any other reason is devoid of oxygen, it may be entirely in the ferrous condition. The removal is accomplished as follows: To the raw

water add enough lime, *a*, to neutralize the free CO_2 present after aeration (1 grain of lime per gallon to each 12 parts per million CO_2); *b*, to precipitate the iron sulphate as ferric hydroxid (requiring 1 grain of lime per gallon to each 35 parts per million of ferric sulphate); *c*, to provide an excess of lime of $\frac{1}{4}$ grain per gallon. If the water contains dissolved or colloidal organic matter or manganese it may be necessary to increase the amount of lime or even to add a coagulant. Aerate the water at entrance to settling basin, and allow from 4 to 12 hours for sedimentation. A long period of sedimentation is necessary in iron removal, otherwise iron and calcium carbonate deposits will form in the filters. Sedimentation should be followed by filtration in the usual manner.

Free Alum ($Al_2(SO_4)_3$) in the Effluent. The logwood test gives indication of the presence of aluminum sulphate in the filtered water, due to incomplete reaction with the alkalinity or lime added to the raw water, and the consequent passing of the alum through the filters in solution. This test is very delicate, but is sometimes affected by abnormal conditions of the raw water. The running of a blank known to contain aluminum sulphate practically eliminates any uncertainty. As a check, test the filtered water for alkalinity with erythrosin. An alkaline reaction proves that no alum is present, while an acid reaction shows the presence of alum. Should the logwood test indicate the presence of alum, while the filtrate is alkaline to erythrosin, it is highly probable that minute particles of aluminum hydroxid are coming through the filter in a colloidal form, due either to the sand being too coarse, the "mat" on the filter being too thin, or too much lime or soda ash, or too little alum (if the coagulation is poor) being used.

It is very important that no free aluminum sulphate be allowed to get into the filtered water, owing to its corrosive and (to a small extent) physiological effects. Positive tests in the filtrate may be due: *a*, most often to not enough lime or soda ash being used to combine with the alum in a water of low alkalinity; *b*, to the filter beds being cracked or dirty, if the settled water is alkaline to erythrosin; *c*, to the use of too much lime or, more often, soda ash, with a turbid river water. When the filtered water is acid to erythrosin, and the logwood test indicates free alum, lime or soda ash should be increased so that the filtrate has a minimum alkalinity of 10 parts per million. If the filtered water is alkaline to erythrosin, and sufficient alkalinity is present in the raw water,

more alum should be added and care should be used to keep a good unbroken mat on the filters. Condition "c" need cause no alarm, the alum present being derived from the clay turbidity of the raw water, some of which is reduced to the colloidal state by the excessive use of lime or soda ash. In the colloidal state (as $Al_2(OH)_6$) it is neither corrosive nor physiologically harmful.

Free Iron ($FeSO_4$) in the Effluent. As with alum, this is indicated by the logwood test and verified by the acidity of the filtrate to erythrosin. The remedies are to increase the amount of lime used so that the settled water gives a faint pink reaction with phenolphthalein and to wash the filters.

Interpretation of Bacterial Tests

A. Raw Water Tests

The 20° C. Gelatin Count. The bacterial colonies developing on the gelatin plates come from a variety of sources. They include those native to natural waters, those washed in with the drainage from fields, pastures, and woods, and those due to pollution by animal and human refuse. The count does not indicate all the bacteria present, experiments by the author indicating that often only 10 per cent. of those present grow on the gelatin plate. However, the forms that do develop are very characteristic.

Normal unpolluted waters of lakes give not over about 200 bacteria per cubic centimeter on gelatin, and any numbers present in excess of this may be taken to indicate contamination by soil wash from fields, or the presence of sewage or putrefactive forms. Even the surface drainage from fields, etc., cannot be regarded as harmless, since it may include elements of human pollution. In fact, a number of typhoid epidemics have occurred during flood periods, when the factor of sewage pollution was minimized by dilution.

Special attention should be given to the form, color, etc., of the colonies, as familiarity with these is often of value in diagnosing the condition of the water.

The 37° C. Agar Count. This will usually be smaller than the gelatin count as it particularly favors the type of bacteria growing at blood temperature, *i.e.*, those present through human or animal pollution. It therefore has considerable significance, especially in its relation to the gelatin count. In very pure waters

not only will the gelatin count be low, but the count on agar will not exceed two or three bacteria per cubic centimeter. In the ordinary run of raw waters, the agar count should be less than 10 per cent. of the gelatin count. In waters heavily polluted with sewage the agar count will approach equality to the gelatin count with increasing pollution.

Red Colonies on Litmus-Lactose-Agar. Here is another step toward direct evidence of fecal pollution, since acid-forming colonies indicate the presence of one or more of the several groups of bacteria whose native habitat is the intestines of warm-blooded animals. Therefore, the presence of red colonies has great significance as an indication of direct pollution.

Fermentation of Lactose Broth. This may be taken as positive evidence of the presence of the colon group of bacilli, which are normal inhabitants of the human intestines and therefore denote direct pollution by human fecal matter. The colon bacillus does not produce disease, but is akin in habitat and living conditions to certain pathogenic bacteria,—typhoid, cholera, etc., so that, if it is present, it is quite possible that the bacteria of these diseases may find their way into the water supply by the same route.

The significance of these tests is not as clean-cut as the above would indicate, as there are exceptions to the rules, but the use of the above interpretations errs on the side of safety.

The main purpose of the raw water tests is to serve as a basis of comparison for the filtered water tests. Furthermore, they serve as a record of raw water conditions, show the necessity for filtration, and give valuable guidance in the operation of the plant.

B. Filtered Water Tests

The 20° C. Gelatin Count. The count on gelatin should generally be less than 100 bacteria per cubic centimeter, except in the case of turbid rivers, where it may run to 200, provided, however, that the agar count and Coli determinations are satisfactory.

Much has been said against the percentage method of rating filter efficiency. It is the actual number of bacteria in the filtered water which is the index of potability, and therefore the reader must not be misled by statements of high percentages of raw water bacteria removed by filtration. However, some small allowance must be made for the fact that when there are large

numbers of bacteria in the raw water, there will be a larger number in the filtered water, although the percentage removal will be high, whereas, with a smaller number in the raw water, there will be less in the filtered water, but a lower percentage removal. This follows from operating conditions and not from any peculiarity of the filtration process. Typical values are given in the following table:

TABLE

RELATION OF RAW TO FILTERED COUNTS ON GELATIN AT 20° C.

Bacteria per cc.		*Per Cent. Removed*
Raw	*Filtered*	
100	35 to 55	55
500	70 to 100	84
1000	80 to 110	90
5000	120 to 160	97
10000	140 to 190	98.5
20000	150 to 200	99.4
30000	160 to 200	99.5
40000	170 to 210	99.55
50000	175 to 225	99.6

This shows the range which should be obtained in the gelatin counts of the filtered water for various counts in the raw water, and shows one way in which the raw water count may aid in interpreting the filtered water count.

The 37° C. Agar Count. This should be very small in the filtered water, and generally below 10 per cc. While evidence is not conclusive, it appears that the agar count should be about 10 per cent. or less of the gelatin count, in which case the values would run from about 4 to 23 per cc., using the above table. Where both gelatin and agar counts for the raw water are available, the ratio of the latter to the former can be obtained, and this same ratio can be applied to the gelatin count of the filtered water to give approximately what the agar count should be.

Red Colonies on Litmus-Lactose-Agar. Red colonies are very significant in filtered water. There should never be more than one or two on a plate, and such positive plates should not occur more than once in ten times on the average. If any plate should show more than three, or if the several plates made on the same day should all show red colonies, or if these occurred with regu-

larity for several consecutive days, even in small numbers, every effort should be made to increase the filtration efficiency by using more coagulant, by more frequent washing, and by careful examination of filter-bed conditions, rate controllers, etc. In the meantime the dose of liquid chlorine should be increased as a temporary measure.

Fermentation of Lactose Broth. This is a very significant test in filtered water. For a direct interpretation of any one day's result, at least 10—10 cc. tests would be necessary, whereas our schedule calls for only one such test per day. However, even if results could be obtained for each day's test, the interval of incubation would bring them too late to act as a warning of dangerous conditions. The filtration-plant operator must therefore use these tests as indication that the plant is delivering water which is continuously satisfactory, and as a guide in establishing operating conditions which will render him confident that there can be no break or interruption in the good quality of the effluent. Viewed in this light, the fermentation tests should be studied in periods of 10 days, monthly, and annually. In the 10-day periods, not more than 30 per cent. of the 10 cc. tests in any such period, nor 10 per cent. of the 1 cc. tests should ever be positive. In the monthly periods a similar proportion is allowable, while in the annual period 40 per cent. of the 10 cc. tests, 5 per cent. of the 1 cc. tests, and 1 per cent. of the 1/10 cc. tests may be positive. In addition, repeated positive tests in 10 cc. for more than 3 consecutive days, and in 1/10 or 1 cc. for 2 consecutive days, or positive results in 1/10, 1, and 10 cc. on the same day should be regarded as a warning calling for immediate remedial measures.

CHAPTER VI

COAGULATION AND STERILIZATION

The purposes of coagulation are to collect the fine suspended matter in the water into clots or masses of a size which will readily settle to the bottom of the sedimentation basins and to form a film over the filter sand which will prevent even the finest suspended particles from passing through. Coagulation also assists in removing color, odors, and tastes from the water, as will be presently explained.

Description of the Process. The process of coagulation is based on the fact that soluble salts of aluminum, iron (in both the ferrous and ferric state), zinc, copper, and some other metals react with solutions of the hydroxids, carbonates, and bicarbonates of the alkalis and alkaline earths to form gelatinous precipitates of the hydroxids of the metals. For economic reasons and because of the poisonous qualities of the salts of some of the other metals, sulphate of aluminum or sulphate of iron are most generally used, the required concentration of hydroxyl ions being supplied by the salts of the alkaline earths naturally present in water, or, in the absence of these in sufficient quantity, by the addition of hydrated lime or soda ash.

When sulphate of aluminum or sulphate of iron (under proper conditions) is added to water, the precipitate takes the form of small flakes about the size of a pin-head, and white (with aluminum) or greenish brown (with iron) in color. Due to their gelatinous form, these flakes sink very slowly—indeed, appear to the eye to be floating in the water. As is commonly the case with reactions between solutions in water, the precipitate tends to form about the particles of silt, bacteria, etc., present, and in traveling through the water, more silt becomes attached to the flakes of coagulum and these unite, one with the other, until quite sizable masses are formed, which either settle to the bottom of the sedimentation basins, or are caught on the filter sand, being too large to pass through the interstices between the grains. Such of the coagulum as is carried over to the filters forms a gelatinous coating over the

surface of, and in the upper part of, the filter sand, which constitutes the real filtering medium. Without proper coagulation, filtration at the high rates used in the mechanical process would be impossible, and its advantage, even with slow sand filters, is becoming evident, as it enables them to operate at higher rates and effects a more complete removal of organic matter.

Theory of Coagulation. Recent experiment and research in this and allied lines of chemistry have brought to light some interesting facts regarding coagulation. When aluminum sulphate or a similar salt is added to water naturally alkaline or rendered so artificially by the addition of lime or soda ash, a reaction takes place, as a result of which an invisible jelly-like substance forms throughout the water. Supposedly this has the structure of a very open-meshed network or sponge. Under suitable conditions this network contracts and breaks up into the flakes of coagulum already described. This change is called flocculation or coagulation. In the present case this flocculation is brought about by the presence of an electrolyte, calcium sulphate, which is one of the by-products of the reaction between aluminum or iron sulphate and the hydroxyl ions present in the water. It may also occur through the presence of fine clay or silica particles in the water, by mechanical agitation of the water or by allowing it to flow over granular or glassy surfaces. The presence of organic matter or vegetable emulsions in the water, or the presence of alkalis in certain concentrations, will at times prevent or seriously retard coagulation.

This network in contracting will envelope or entrap particles of silt, bacteria, etc. The resulting flakes have a very fine sponge-like structure, which enables them to absorb coloring matter and gases in solution in the water. It is another peculiarity of this coagulum that by its presence clay, silt, organic matter, etc., which may be present in a very finely divided condition, are caused to coagulate and precipitate.

The portion of the coagulum which is carried over on to the filters forms over the sand a film or layer of gelatinous substance perforated by very fine pores, through which water readily passes, but which are impenetrable to fine suspended matter or even to matter in pseudo-solution. This film on the filters also has an absorptive action on the water passing through it, removing therefrom coloring matter and odors or tastes.

Chemicals Used in Coagulation. The chemicals used in the process of coagulation are: aluminum sulphate, iron sulphate, quicklime, hydrated lime, and soda ash. The properties and characteristics of these chemicals, their use and their reactions in water purification are described in the following paragraphs.

Aluminum Sulphate. Aluminum sulphate ($Al_2(SO_4)_3 18H_2O$), commonly called "filter alum," in its purest commercial form con-

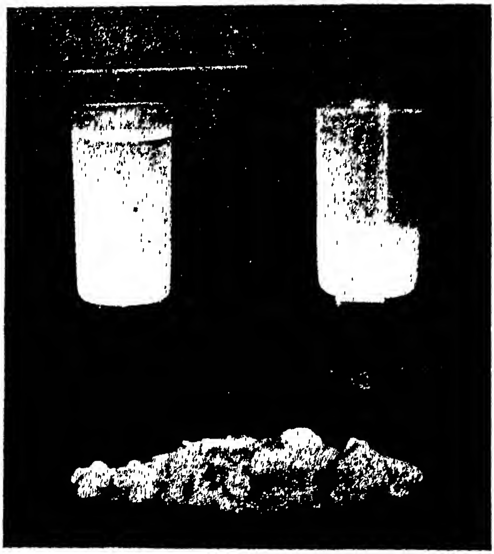


FIG. 73.—Aluminum Sulphate and Coagulation.

sists of small lumps (½ to 2½ inches in size), hard, having a greasy feel and an opaque, greenish-white color. It should contain 51 per cent aluminum sulphate and 49 per cent water of hydration, but owing to the process of manufacture the composition may vary, and some authorities assign to the commercial product the formula $Al_2(SO_4)_3 16H_2O$. Theoretically it should contain 15.3 per cent of water-soluble alumina (Al_2O_3), but it is generally specified to contain not less than 17 per cent, being known as "basic" aluminum sulphate. It should not contain more than 0.5 per cent of matter insoluble in cold distilled water. Impure "alum" generally has a distinct brownish tinge. Aluminum sulphate may be obtained in carload lots, or in barrels which weigh about 380 pounds gross.

Alum is used as a coagulant in conjunction with slaked lime, soda ash, or the natural alkalinity of the raw water. The chemical reactions are as follows:

1. Alum and lime,

$$Al_2(SO_4)_3+3Ca(OH)_2=Al_2(OH)_6+3CaSO_4$$

2. Alum and soda ash,

$$Al_2(SO_4)_3+3Na_2CO_3+3H_2O=Al_2(OH)_6+3Na_2SO_4+3CO_2$$

3. Alum and alkalinity (as $CaCO_3,H_2CO_3$),

$$Al_2(SO_4)_3+3CaCO_3,H_2CO_3=Al_2(OH)_6+3CaSO_4+6CO_2$$

In all three reactions the effective coagulum formed is aluminum hydroxid ($Al_2(OH)_6$), which appears as a flocculent precipitate. In reactions 1 and 3, calcium sulphate ($CaSO_4$), and in reaction 2, sodium sulphate (Na_2SO_4), are formed and remain in solution. Calcium sulphate causes permanent hardness and is objectionable, especially in boiler-feed water, forming a very hard scale. The increase in permanent hardness is 10.4 parts per million, or about 0.6 grain per gallon for each grain per gallon of aluminum sulphate used. The sodium sulphate is unobjectionable in the amounts present. In reactions 2 and 3, carbonic acid (CO_2) is an objectionable by-product, especially in waters of low alkalinity, owing to its corrosive action. Thus reaction 3, most commonly used because cheapest, gives an effluent containing two objectionable constituents, and reactions 1 and 2 an effluent containing one objectionable constituent. The ideal way, and the most expensive, would be to use reaction 2, and add sufficient lime or soda ash to neutralize the carbonic acid. This may be necessary in treating waters of low alkalinity where the corrosive action of the carbonic acid causes trouble, although it may be possible to remove part of the CO_2 by reaeration after filtration. The carbonic acid also gives the water an increased tendency toward algæ growths, which often become abundant when filtered water is stored in open reservoirs.

If sufficient alkalinity, natural or artificial, is not present to react with the aluminum sulphate, *basic* sulphates will form. These are soluble, so that no coagulation will appear under such conditions. The reactions, using natural alkalinity, are:

$$Al_2(SO_4)_3+CaCO_3H_2CO_3=Al_2(SO_4)_2(OH)_2+CaSO_4+2CO_2$$

$$2Al_2(SO_4)_3+3CaCO_3H_2CO_3=Al_2(SO_4)_3Al_2(OH)_6+3CaSO_4+6CO_2$$

$$Al_2(SO_4)_3+2CaCO_3H_2CO_3=Al_2SO_4(OH)_4+2CaSO_4+4CO_2$$

Any one of these reactions may take place, depending on conditions. This accounts for the difficulty of obtaining coagulation sometimes met with, especially in winter, when the reactions are slow and the coagulum formed would combine with the aluminum sulphate still in solution. Under cold-weather conditions some of the alum may pass through the filters in this soluble basic form, the reaction being completed in the clear-water basin, causing the formation of minute specks of coagulum in the filtrate. Using more lime or soda ash will tend to remedy this condition, which is most apt to occur when, in addition to low temperature, the water is low in alkalinity.

The presence of alkalis (sodium and potassium) in the water may cause a failure to coagulate, the hydroxid forming as a colloidal solution, which does not assist in clarifying the water and will pass through the filters, giving the effluent a smoky appearance. A decrease in lime or an increase in alum will assist in overcoming this.

"Alum" is very successful in removing color caused by the tannates and gallates in swamp water. One grain per gallon of aluminum sulphate will remove about 10 parts per million of color, but this varies with different waters, the color being harder to remove in some cases than in others. It also removes organic matter, as has been mentioned.

The amount of aluminum sulphate to use generally depends on the turbidity of the raw water. With clear water a minimum of 0.3 grain per gallon should always be used, and it may be necessary to increase this up to 2 grains per gallon, according to the pollution of the stream, which in this case governs. With turbid waters the suspended clay has considerable affinity for the organic matter which causes pollution, removing much of it by absorptive action, and the bacterial reduction is roughly proportional to the reduction in turbidity, therefore the latter is used as a convenient measure of the amount of coagulant required. As shown by Plate III, the amount of aluminum sulphate required increases with the turbidity, but less is generally required with coarse turbidity than with fine. With very turbid waters, some of the aluminum sulphate and aluminum hydroxid is absorbed by the clay in suspension, and an additional allowance must be made for this. No two waters have the same alum-turbidity ratio, and it is recommended that each operator should determine by experiment

the most economic amount of chemical for different turbidities, and plot a curve on Plate III covering the particular case of the water he is treating.

The final test for the proper amount of aluminum sulphate to use is of course the clarity of, and bacterial removal in, the filtrate. The size of the flakes of coagulum should be about that of half a pin-head. If the coagulated water appears clear or smoky, with no flakes visible, more alum should be used, unless the alkalinity is very close to a minimum required to decompose the alum being used, in which case add more lime or soda ash. The smoky or "pin-point" coagulation is most common in winter, owing to the more sluggish action of the chemicals. If the flakes are large and feathery, the amount of alum should be decreased.

The aluminum sulphate will react directly with the natural alkalinity in the water if there is sufficient of the latter. Each grain per gallon requires for complete reaction 10 parts per million of natural alkalinity, as determined by the erythrosin test, and there should be an excess of alkalinity of at least 10 parts over that required by the alum. Any deficiency in alkalinity must be corrected by adding lime or soda ash to the raw water, 0.35 grain of lime or 0.5 grain of soda ash being required per grain of alum.

These relations are shown by Plate IV for quick and slaked lime, and by Plate V for soda ash, used in conjunction with aluminum sulphate. The lower margin gives the amount of lime or soda ash required to supplement deficiencies in alkalinity. The use of these charts in connection with Plate III is shown by the following examples. It is recommended that the "medium" curve on Plate III be used with a new water and to serve as a guide in plotting the alum-turbidity curve, as mentioned above. In the interests of economy, the operator should endeavor to use as little coagulant as is consistent with good results.

Example 1. Analysis of raw water:

Turbidity,	800	parts per million
Alkalinity,	50	parts per million
Free CO_2,	0	part per million

On Plate III, left-hand margin, find turbidity 800. Follow the horizontal line through this point to the right until it intersects the "medium" curve. Follow the vertical line down from the intersection and read 2.5 grains per gallon of aluminum sulphate

at the lower margin. To find the equivalent pounds per million gallons follow up vertically from 2.5 grains to the intersection with the line marked "Conversion Line-Grains per Gallon to Pounds per Million Gallons," then horizontally to the right-hand margin, where read 357 pounds. If three million gallons of raw water are being pumped per day, the amount of alum required will be 3×357, or 1,071 pounds per day. On Plate IV, find the intersection of the 2.5 grain per gallon diagonal with the left-hand margin and note that the minimum alkalinity required without lime is 35. Therefore, an alkalinity of 50 is ample and no lime is required. Following the horizontal line from alkalinity 35 to its intersection with the line marked "Increase in CO_2" then vertically to the upper margin shows that the free carbonic acid in the settled water as delivered to the filters will be increased 17 parts per million. The CO_2 in the filtered water will not be increased that amount, as part of this gas will be liberated and collect in the filters, due to the pressure in the sand being below atmospheric. Following from the intersection of the 2.5 grain diagonal with the horizontal line marked "No increase in CO_2" vertically upward to intersection with the line marked "Permanent Hardness," then horizontally to the right-hand margin, read "Increase in Permanent Hardness as $CaSO_4$" 26.25 parts per million.

Example 2. Analysis of raw water:

Turbidity,	250	parts per million
Alkalinity,	20	parts per million
Free CO_2,	5	parts per million

On Plate III for turbidity 250, find alum required, 1.85 grains per gallon, or 264 pounds per million gallons. On Plate IV, estimating the point between the 1.5 grain per gallon and the 2 grain per gallon diagonal at which 1.85 would come, follow this imaginary diagonal to the right until it intersects the horizontal line through 20 alkalinity. From this intersection follow vertically downward until the horizontal line through "O" is reached, and then follow the diagonal lines downward and toward the right until the horizontal line through 5 on the "H_2SO_4 Acidity and Free CO_2" scale is reached. From this point follow vertically downward, and read lime required as 0.55 grain per gallon. To get the result in pounds per million gallons, follow vertically upward from 0.55 to the con-

version line, then to the right-hand margin, reading 79 pounds per million gallons. In this case the increase in CO_2 due to the alum reaction is 6.8 parts per million, obtained by following the 20 alkalinity line to the right until it intersects the "Increase in CO_2" line, then upward to the upper margin. The increase in permanent hardness in this case is 19.5 parts per million.

Example 3. Analysis of raw water:

Turbidity,	500 parts per million
Alkalinity,	63 parts per million
Free CO_2,	8 parts per million

Required that the treated water shall contain no Free CO_2. On Plate III, for turbidity 500, find alum required 2.0 grains per gallon, or 286 pounds per million gallons, using the "medium" curve. On Plate IV, follow the 2.0 grain per gallon diagonal down to the horizontal line marked "Line for No Increase in CO_2." Then continue along the 2-grain-per-gallon line downward and diagonally to the right until it intersects the horizontal line through 8 on the "H_2SO_4 Acidity and Free CO_2" scale. Then vertically downward to 1.1 grains per gallon on the lime scale, which is equivalent to 157 pounds per million gallons. This will give a water free from the corrosive action of carbonic acid. The increase in permanent hardness will not be affected, being 21 parts per million in this case.

Example 4. In mining regions the water is rendered acid by the sulphuric acid, iron and aluminum sulphate from the mine waste. Such a water gives a negative test for alkalinity as evidenced by the sample remaining white when erythrosin is added, and is therefore titrated with sodium carbonate, the results being recorded as "H_2SO_4 Acidity." Such a water may analyze as follows:

Turbidity,	3 parts per million
Alkalinity,	0 part per million
H_2SO_4 acidity,	12 parts per million
Free CO_2,	3 parts per million

On Plate III, for turbidity 3, find alum required 0.3 grain per gallon, or 43 pounds per million gallons. On Plate IV, following a proportional distance below the 0.5 grain per gallon line (the lowest one), find the intersection with the horizontal line through

15 on the "H_2SO_4 Acidity and Free CO_2" scale, thence vertically downward to lime required 0.86 grain per gallon, or 123 pounds per million gallons. Note that the acidity and CO_2 are added $(12+3=15)$, and considered together. If analyses show a considerable amount of iron present in addition to the sulphuric acid, a reduction in the amount of alum may be made, as will be explained later.

Aluminum sulphate is very soluble in water and solutions are easily prepared. The required amount is weighed out and placed in a perforated box over the solution tank, see Fig. 8, and hot water is sprayed over it, which dissolves the alum and washes it into the solution tank. Enough water is added to make up a solution of proper strength, which is thoroughly mixed by means of the revolving paddles in the solution tank. It is not necessary to operate the paddles after the solution is made up. For amounts of water required see Plate XI and page 168; see also the chapter on general operation. The strength of solution used is generally between 3 and 6 per cent. Alum may also be fed dry by means of automatic scales, such as were described for lime in connection with the Columbus plant. Under such conditions it is generally necessary to crush it quite fine, generally to half-inch lumps or finer.

Lime. Quicklime or calcium oxid (CaO) is used with aluminum and ferrous sulphate in coagulation, furnishing the hydroxyl ions (OH'), necessary to the formation of aluminum and iron hydroxid ($Al_2(OH)_6$ and $Fe(OH)_2$). It is also used in water-softening. In appearance it is a white, chalky substance, usually in both lumps and powder. For convenience in handling it should be specified to be crushed, so that no lumps exceed 2 inches in largest dimension. If it is to be weighed out automatically, it should preferably be crushed to ¾ inch or smaller. Lime contains a variable amount of impurities, depending on the region from which the limestone from which it is prepared is obtained, and the care used in burning. Some limes contain only 50 per cent of water-soluble calcium oxid, but those used for coagulative purposes generally run from 75 to 99 per cent. Unless the source of supply is too remote, a high calcium lime should be obtained, as it is more satisfactory to use, slaking more rapidly, reacting more readily in solution, etc. A higher price (delivered at the plant) is justified for a high calcium lime over that for a leaner one. Thus if lime from one kiln analyzing 80 per cent CaO costs 24

cents per 100 pounds, and that from another analyzes 90 per cent CaO, the latter is to be preferred at any price up to 9/8 of 24, or 27 cents.

Lime can be obtained in bags, barrels, or in bulk, by carload lots. It should be fresh-burned when bought, as it deteriorates with storage. For this reason, if bought in barrels or bags, large quantities should not be kept on hand, as the carbonic acid in the air will partially change it into calcium carbonate. In a moist atmosphere it will slake, expanding in volume in so doing, and bursting the containing package. In the larger plants it is stored in air-tight concrete bins, which is undoubtedly the best method.

If possible it should be bought on a guaranteed percentage of calcium oxid, a sample of each shipment being analyzed (see Appendix A). If the analysis falls below the guarantee a deduction should be made; if it is above the guaranteed amount, a bonus should be paid.

Quicklime must be slaked before use, by adding water to it, thereby converting it into calcium hydroxid, the reaction being:

$$CaO + H_2O = Ca(OH)_2$$

The slaking should be very carefully done, as on it depends the success of the lime treatment. In large plants it is usually accomplished in iron tanks, the lime and water being mixed with motor-driven rakes. In small plants an iron trough or slaking box is used. It is well to use a minimum amount of water and to cover the lime while slaking, allowing it to heat up during the process. Also the lime and water must be mixed so that every part thereof comes in intimate contact with the water. Theoretically it takes ⅓ as much water as lime, but practically about 4 times as much water by weight as lime is required. The water used should be as hot as possible, so that the temperature during slaking may be high, if possible 200° Fahr. A 95 per cent lime requires about 15 to 30 minutes to slake thoroughly under *optimum* conditions, and the leaner a lime is the longer it requires. If possible, the lime for each shift should be slaked in the shift before.

The slaked lime is diluted with water and kept in solution tanks, from which it is fed to the raw water through an orifice box. At least four times as much water by weight as slaked lime is required to make a satisfactory dilution, and the water used in this case should be as cold as possible, as calcium hydroxid is more soluble in cold water.

Stirring paddles in the solution tanks must be kept going constantly, in order to keep the lime in suspension. Owing to its clogging nature, the orifice boxes and piping through which it flows must be carefully watched and frequently cleaned to prevent choking. If the lime solution is introduced into the raw water by means of a single pipe, entering as a solid stream, much of it will fall to the bottom and be lost. It is best introduced through a pipe or grid with comparatively large perforation, say, $3/8$ or $1/2$ inch, using a solution as dilute as possible.

Unless the above precautions as to proper storage, slaking, and introduction are observed, a large loss will result, which may be as much as 50 per cent. By proper handling this loss may be reduced to 10 or 15 per cent.

The use of an excess of lime should be avoided, as it renders the water caustic. This is best done by keeping the dose of lime within the limits dictated by the tests for free and half-bound carbonic acid, and the amount required to react with the coagulant used, as indicated by the Plates. The treated water can also be tested for alkalinity with both phenolphthalein and erythrosin. The alkalinity with the former indicator should not exceed half of that with the latter. This does not necessarily mean that there is no caustic alkalinity present, but indicates that lime is present in correct quantity to react with all the bicarbonates, given sufficient time for the completion of the reaction. Another test for calcium hydroxid consists in adding a few drops of dilute silver nitrate solution to a sample of water in a test tube. A grayish brown precipitate indicates the presence of calcium hydroxid (caustic alkalinity). This test is not reliable with waters containing chlorids in appreciable quantities.

Hydrated Lime. Hydrated lime ($Ca(OH)_2$) may be obtained in paper bags of 40 pounds each, or in duck bags of 100 pounds (a rebate is allowed on the bags). It has several advantages over quicklime. It need not be slaked, and the losses and danger from improper slaking are thus avoided. It does not deteriorate in storage. It is purer than most quicklimes. The accrued savings from these several sources compensate for its greater weight, so that it may be substituted in Plate IV without change. It may be mixed directly in coagulant tanks and fed to the orifice boxes as an emulsion, in which case the same precautions against clogging as for quicklime must be observed. Or it may be fed in powdered

form into a stream of running water by means of a screw feed, the stream, after receiving the lime, falling into a funnel and flowing through a pipe into the raw-water main. The screw feed is driven

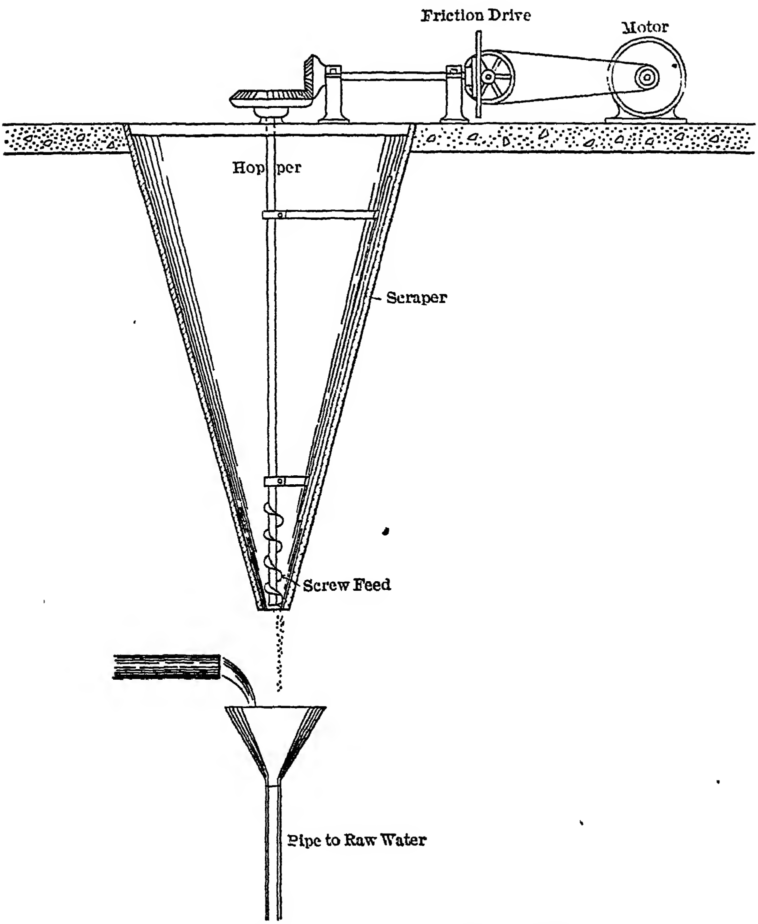


FIG. 74.—Dry Chemical Feeding Device.

by a water motor through a friction drive which allows for regulating the speed of the screw. Suitable reduction gearing is provided for lowering the speed of the motor to that required for the screw. The freedom from clogging and positiveness of feed with this method are obvious. To prevent the lime in the hopper

from arching, a scraper attached to the screw shaft is added. (Fig. 74.)*

Hydrated lime costs more than quicklime, owing to its increased weight (caused by the water of hydration), which is 32 per cent greater than quicklime for the same amount of calcium oxid.

Soda Ash. This is anhydrous sodium carbonate (Na_2CO_3). It is a fine white powder and is generally obtainable in duck bags of 100 pounds each (a rebate is allowed on the bags). It should be specified to contain 98 per cent pure sodium carbonate, and not over 0.5 per cent insoluble matter.

It is used with alum in the same manner as lime and in the proportions shown graphically by Plate V. It may also be used for the removal of free CO_2, and for acid correction. It has the advantage of not increasing the permanent hardness of the water, and is much easier to handle than lime, dissolving readily, not requiring stirring in the coagulant tanks, and not clogging orifice boxes or piping. By its use after-precipitation of calcium carbonate on the filter sand and in the mains is avoided—an important point. Used with alum in the proportions required for the theoretic reaction, 0.5 grain per gallon per grain of aluminum sulphate, a small amount of free carbonic acid is produced, half as much as when the alum reacts with the natural alkalinity. By using equal amounts of soda ash and alum no free carbonic acid is formed. Soda ash is very much used in small plants, owing to the convenience in handling and because not such great care is required to use the exact proportions as with lime, also where the settling capacity is limited, say, less than 4 to 6 hours, lime would cause trouble by after-precipitation, while soda ash does not. Its principal disadvantage is its cost, as more is required than of lime, and its price is about three times as great. (See paragraph on comparative costs.)

The following examples will explain the use of Plate V in determining the amount of soda ash to use:

Example 1. Analysis of raw water:

Turbidity,	800	parts per million
Alkalinity,	50	parts per million
Free CO_2,	0	part per million

* South Pittsburgh Water Co.

As before, the amount of alum, as determined from Plate III, is 2.5 grains per gallon. Referring to Plate V, it will be seen that for 2.5 grains an alkalinity of 35 is required, so that no soda ash is needed. Referring to the line "Increase in CO_2 Using Natural Alkalinity," this will be found to be 17 parts per million, as in Example 1, under lime. The permanent hardness is not given, but can be found from Plate IV. For 2.5 grains this is 26.25 parts per million.

Example 2. Analysis of raw water:

Turbidity,	250	parts per million
Alkalinity,	20	parts per million
Free CO_2,	5	parts per million

On Plate III, for turbidity 250, find alum required 1.85 grains per gallon. On Plate V, estimating the point between the 1.5 grains per gallon and the 2 grains per gallon diagonal at which 1.85 would come, follow this imaginary diagonal to the right until it intersects the horizontal line through 20 alkalinity. From this intersection follow down vertically to the 0 horizontal, then diagonally to the right, paralleling the dashed lines marked "Lines for Removal of CO_2" until the horizontal line through 5 on the "H_2SO_4 Acidity and Free CO_2" scale is reached. Following vertically downward from this point, read 1.2 grains per gallon on the soda-ash scale, which by the conversion line is found to be 172 pounds per million gallons. The increase in CO_2 due to the reaction of the alum and natural alkalinity is 6.8 parts per million, obtained by following the 20 alkalinity line to the right until it intersects the line marked "Increase in CO_2 Using Natural Alkalinity," then upward to the upper margin. Such a treatment would be used where it is desired not to remove all the CO_2, but to keep this below a certain amount, say 10 parts per million. This is sometimes done for economic reasons, and is not very objectionable if the water is fairly high in alkalinity.

Example 3. Analysis of raw water:

Turbidity,	500	parts per million
Alkalinity,	63	parts per million
Free CO_2,	8	parts per million

Required that the treated water shall contain no CO_2. On Plate III, for turbidity 500, find alum required 2 grains per gallon. On

Plate V, follow the dashed line for 2 grains per gallon diagonally to the right, then downward and again to the right, until it intersects the horizontal line through 8 on the "H_2SO_4 Acidity and Free CO_2" scale. Then vertically downward to the soda-ash scale, reading 3.2 grains per gallon, which by the conversion scale is found to be 458 pounds per million gallons.

Example 4. Analysis of raw water:

Turbidity,	3 parts per million
Alkalinity,	0 part per million
H_2SO_4 acidity,	12 parts per million

On Plate III, for turbidity 3, find alum required 0.3 grain per gallon. On Plate V, following a proportional distance below the 0.5 grain per gallon line (the lowest one) diagonally to the right, then vertically downward and again to the right, paralleling the solid diagonal lines marked "Lines for Removal of H_2SO_4," until the horizontal through 12 on the "H_2SO_4 Acidity and Free CO_2" scale is intersected. Thence vertically downward, reading 0.93 grain per gallon on the soda scale. There would be a formation of CO_2 using this amount of soda ash. If a CO_2-free water is desired use the dashed lines both for the alum and the acid, as in Example III. If both CO_2 and sulphuric acid occur, add them together, and use the dashed lines to secure a complete removal.

Soda ash may be dissolved and fed to the water in the same manner as aluminum sulphate, using a dissolving box and solution tank arranged as in Fig. 8. The solution should not exceed 5 per cent in strength. Stirring is necessary only while making up the solution. It may also be fed to the water by means of the device described for use with hydrated lime, as well as with automatic scales of the type used at the Columbus plant.

Ferrous Sulphate. Ferrous sulphate, in conjunction with lime, is extensively used as a coagulant. The commercial product consists of transparent green lumps, composed of the crystals of the salt. It is quite pure, running from 95 per cent ferrous sulphate upward. Its chemical formula is $FeSO_4,7H_2O$, containing seven molecules of water. On prolonged exposure to the air, the surface is slightly oxidized, forming ferric sulphate and iron oxid.

A second form, known as "sugar of iron," is also used. This is partially dehydrated, containing less than seven molecules of water of crystallization, so that it contains over 100 per cent of ferrous

sulphate ($FeSO_4,7H_2O$). It is quite pure, containing less than 1 per cent of foreign matter. In appearance it is granular, like sugar, making it very convenient for use in dry feeding as described under hydrated lime (see Fig. 74), the same type of apparatus being used.

Its advantages are that the cost of treatment is generally cheaper than with alum, especially with very turbid waters, and

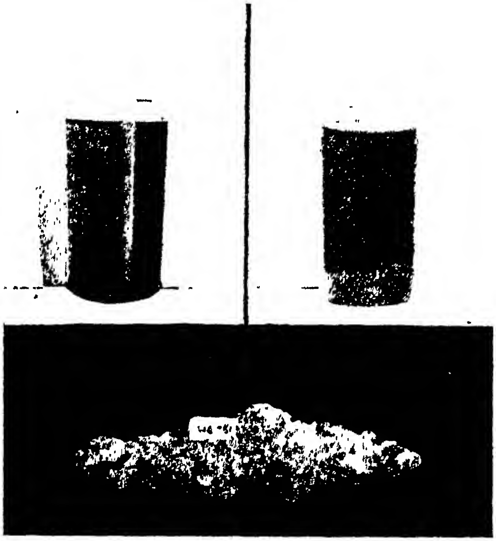


FIG. 75.—Iron Sulphate and Coagulation.

that the coagulum or "flock" formed is of greater specific gravity than in the case of alum, causing a more rapid sedimentation. Also, the ferrous and ferric sulphate seem to have a direct germicidal action to a certain extent. On the other hand, the use of lime is required at all times, with its concomitant danger of trouble from after-precipitation, if it is not carefully gaged, due to the reaction of the surplus with the bicarbonate alkalinity, the resulting product, calcium carbonate, being slow to form and settle out. It cannot well be used with colored swamp water, as the ferrous sulphate forms complex soluble compounds with the organic matter present, which often give the water a blackish tinge. It is difficult to use with soft waters, as any surplus lime would make the water caustic, also soft waters are very apt to be highly colored. For these reasons this process has found its most extensive and suc-

cessful application to turbid waters of fairly high alkalinity, such as those of the Mississippi and Missouri River valleys.

The reactions may be considered in two ways: if the lime is added before the ferrous sulphate the two react directly:

$$FeSO_4 + Ca(OH)_2 = Fe(OH)_2 + CaSO_4$$

If the ferrous sulphate is added first, the reactions are more complex. The sulphate reacts with the bicarbonates in the water, forming a bicarbonate of iron, which stays in solution:

$$FeSO_4 + CaCO_3H_2CO_3 = FeCO_3H_2CO_3 + CaSO_4$$

This would oxidize and precipitate, but the reaction is slow and the precipitate often forms in a finely divided state, so that lime is added to complete the reaction:

$$FeCO_3H_2CO_3 + Ca(OH)_2 = Fe(OH)_2 + CaCO_3H_2CO_3$$

The effective coagulum is the ferrous hydroxid $Fe(OH)_2$, a gelatinous precipitate. In its pure form this is white, slightly soluble, giving the water a ferruginous taste. It is rapidly oxidized by the dissolved oxygen in the water, according to the reaction,

$$4Fe(OH)_2 + 2H_2O + O_2 = 2Fe_2(OH)_6$$

The ferric hydroxid formed ($Fe_2(OH)_6$) is an insoluble gelatinous precipitate of a brown color. In practice intermediate (ferro-ferric) hydroxids of a green color are often formed, particularly if some of the ferrous sulphate is oxidized to ferric before the lime reacts with it. After precipitating, the ferro-ferric and ferric hydroxids may be converted into iron oxids, by the splitting off of the water of hydration:

$$Fe_2(OH)_6 = Fe_2O_3 + 3H_2O$$

these oxids forming a heavy silt varying in color from yellow to brown, or almost black (due to the presence of dehydrated ferro-ferric hydroxid). The amount of dissolved oxygen required in the water for these reactions is not large, 0.5 part per million being required for each grain per gallon of ferrous sulphate. A normal stream should contain at least 5 parts per million of dissolved oxygen, even in midsummer, so that it would take care of 10 grains per gallon of iron. A badly polluted stream might contain only 2 parts of oxygen during the same season, causing some trouble, due to the solubility and taste of the unoxidized ferrous hydroxid.

Theoretically, the amount of lime required is 0.24 grain of 85

per cent CaO for each grain of ferrous sulphate. Practically the minimum used is about 0.4 grain per grain of iron (see sources of loss under "Lime"), and it is sometimes an advantage to increase the lime, if sufficient alkalinity is present, as the resulting calcium carbonate crystallizes about the ferric hydroxid and increases its weight and rapidity of settling. The amount of calcium sulphate formed is 8.44 parts per million for each grain per gallon ferrous sulphate.

In addition to the coagulative effect, we have somewhat of the "adsorptive" action toward dissolved matters, found in the case of aluminum sulphate, and, in addition, ferric sulphate will precipitate nitrogenous organic matters in solution as non-putrefactive compounds.

In practical operation, at least enough lime must be added to: 1st, combine with the iron sulphate; 2d, to remove any CO_2 that may be present; 3d, to give a slight excess, 1 to 5 parts per million. The treated water should be faintly pink with phenolphthalein. The amount of lime used is generally increased with the turbidity. Commencing with 0.4 grain for a practically clear water, the increase would be such that the amounts of lime and ferrous sulphate would be equal for a turbidity of about 1,200, the lime increasing still farther for higher turbidities. These relations are diagrammed on Plate VI, which shows the relations between the turbidity of the water and the amounts of ferrous sulphate and lime, also giving a curve for converting grains per gallon of lime or sulphate to pounds per million gallons, and another curve for converting Hazen Reciprocal Turbidity to the United States Geological Survey Standard, which will be found convenient in the older plants, where the former standard may be in use. Of course the amount of lime used must be governed by the bicarbonate alkalinity of the raw water, no more being used than can combine with the bicarbonates and the ferrous sulphate.

The proper amounts of lime and iron under any given conditions can be most readily determined from Plates VI and VII, as illustrated in the following examples:

Example 1. Analysis of raw water:

Turbidity,	400 parts per million
Bicarbonates,	60 parts per million
Free CO_2,	10 parts per million

On Plate VI, tracing to the right along the horizontal through 400 turbidity until the "Turbidity-Ferrous Sulphate Curve" is reached, then vertically downward, read 1.83 on the lower scale, "Ferrous Sulphate ($FeSO_4 7H_2O$) in Grains per Gallon." In a similar manner determine the corresponding amount of lime as 1.15 grains per gallon (on the lower scale). By means of the "Conversion Line—Grains per Gallon to Pounds per Million Gallons," these are found to be equal to 262 and 165 pounds per million gallons for ferrous sulphate and lime (85 per cent CaO or 95 per cent hydrate), respectively, reading the values from the scale on the right margin. Note that both of these values are approximate, varying with different waters, and that the operator, when once familiar with the water he is treating, should vary from these curves according to the dictates of his experience.

Referring to Plate VII, tracing horizontally to the right from 1.83 grains per gallon on the Iron Sulphate scale, and vertically upward from 1.15 grains per gallon on the Lime scale, follow from the intersection of these lines downward parallel to the diagonals until the "Lime-Alkalinity Relation" line is reached, then horizontally to the "Bicarbonate Alkalinity" scale on the right, where read 15 parts per million as the required amount for this relation of iron and lime. Therefore the bicarbonates in the water (60 p.p.m.) are ample to react with the surplus of lime being used. To find the total lime required, including that for CO_2 removal, trace upward from 1.15 on the Lime scale to the 0 horizontal, then follow the diagonals downward and to the right until the horizontal through 10 on the "H_2SO_4 Acidity and Free CO_2" scale is reached, then vertically downward, reading 1.65 on the Lime scale. By means of the conversion line this is found to equal 236 pounds per million gallons. The increase in permanent hardness is found by tracing horizontally to the right from 1.83 on the "Iron Sulphate" scale until the line marked "Increase in Permanent Hardness" is reached, then vertically upward to the "Permanent Hardness" scale, where read 15.4 parts per million.

Example 2. Analysis of raw water:

Turbidity,	2,000 parts per million
Bicarbonates,	57 parts per million
Free CO_2,	12 parts per million

From Plate VI, for a turbidity of 2,000, find the amount of ferrous

sulphate required to be 4 grains per gallon. It is evident that the low bicarbonate alkalinity may limit the amount of lime which can be used. To determine the maximum amount of lime allowable, refer to Plate VII. Find 57 on the " Bicarbonate Alkalinity " scale and trace horizontally to the left until the " Lime-Alkalinity " curve is reached, then proceed upward along the diagonal until on the horizontal through 4 grains per gallon on the " Iron Sulphate " scale. From this point drop vertically to the 0 horizontal and follow the diagonal for CO_2 correction. When on the horizontal through 12 on the " H_2SO_4 Acidity and Free CO_2" scale, drop vertically to the Lime scale, where read 4.05 grains per gallon of lime, or by the conversion line, 580 pounds per million gallons. The increase in permanent hardness for 4 grains per gallon of iron sulphate is found, from Plate VII, to be 33.7 parts per million.

In the case of a water containing no alkalinity and both H_2SO_4 acidity and free CO_2, use the minimum amount of lime to combine with the ferrous sulphate, and, adding the H_2SO_4 and CO_2 together, determine from the CO_2 diagonals the additional amount of lime required to counteract these acidities.

As already said, an excess of lime should be carefully avoided, as most of the troubles experienced with the iron and lime treatment result from this cause.

In most waters it is found best to introduce the lime first, as if the iron is added first, the bicarbonate of iron formed is not so readily acted upon by the lime, or, at most, is reduced to a carbonate, which is apt to give a fine powdery sediment, very difficult to settle out.

An excess of iron is most likely to result with acid water, and is indicated by the logwood test on the settled water and by the fact that the settled water is acid with erythrosin. The obvious remedy is more lime.

A thorough mixing of the chemicals is most essential to the success of this process, but it must not be too violent, as the coagulum is very delicate. For the same reason the flow through the settling basin should be unbroken, and the rate of filtration lowered to 100 million gallons per acre per day.

Solutions of crystalline ferrous sulphate are made in a manner precisely similar to that used for aluminum sulphate and with the same arrangement of dissolving box and solution tank. Difficulty is sometimes experienced due to the oxidation of the solution to the

ferric condition. This can be avoided to a large extent by providing covers for the tanks and reducing the stirring to a minimum. Crystalline ferrous sulphate cannot be fed in the dry form, as to do so would require that it be crushed to a small size. On being crushed it becomes moist and cakes badly.

Sugar of iron may also be fed as a solution, but is particularly adapted for use where a dry feed is desirable. It may be fed by means of the device shown for hydrated lime, Fig. 74, or by measurement through an orifice, since it will flow quite freely in the dry state. Solutions of iron sulphate should not be stronger than 6 per cent.

Natural Coagulation. Acid mine waters sometimes contain natural sulphates of aluminum and iron, the latter being most frequent. In such a case it is only necessary to add the proper amount of lime to obtain a good coagulation, or, if not sufficient, it may be supplemented with ferrous or aluminum sulphate. If the amounts of iron and acidity (as H_2SO_4) have been determined, the equivalent coagulating value in terms of ferrous sulphate may be found from Plate VIII, and the amount of alum or iron required may be reduced to this extent. This is illustrated by the following examples:

Example 1.

Iron in raw water,	10 parts per million
Acidity of raw water,	25 parts per million
Amount alum being used,	4 grains per gallon

Follow the horizontal through 10 on the "Iron in Parts per Million" scale to the right until the heavy diagonal line is reached. Tracing from this point vertically upward, the coagulating value may be read, and tracing downward and to the right, paralleling the diagonal lines, gives the required acidity. In this case the coagulating value is equivalent to 2.85 grains per gallon of ferrous sulphate and the required acidity is 17.5 parts per million, which, being less than the acidity of the raw water, is satisfactory. The amount of alum which must be added to give a coagulant equivalent of 4 grains per gallon is 4.00 minus 2.85 or 1.15 grains per gallon.

Example 2. Suppose that in Example 1 the acidity had been only 10 parts per million. In this case it would govern the coagulating value. The procedure would then consist in following the diagonal upward from 10 on the "Required Acidity" scale to its

termination in the heavy line, then vertically upward to the upper margin, where the coagulating value is found to be 1.62 grains per gallon.

Introduction of Chemicals. Very commonly the chemicals used in coagulation are introduced through separate pipes into the main leading from the raw-water pumps to the sedimentation basin, and while this is moderately satisfactory under ordinary conditions, it is often an advantage to apply the chemicals at some other point, or at several points. If the raw water contains a large amount of heavy sediment or clay, as during a flood, it would be useless to introduce any chemicals before the water enters the basin, as a portion of these would be absorbed by the clay and the remainder carried down with the clay particles soon after entering. In such a case it is advisable to let the heavy suspended matter settle out in the first half of the basin without coagulation, and apply the chemicals near the center of the basin, using a perforated pipe extending across the basin. If the raw water is very clear, so that no coagulation is required to assist in removing the " turbidity " (the suspended matter being generally gaged and known by this characteristic), and no organic matter is present, the chemicals necessary to form the gelatinous " mat " on the filters are best added as the water is leaving the sedimentation basin. For river waters and others subject to large fluctuations in turbidity, provision should be made for the introduction of chemicals into the raw-water main, across the center of the basin, and at the outlet to same, and the point of introduction should be varied with the condition of the raw water.

The chemicals should be thoroughly mixed with the raw water, but violent agitation in mixing is to be avoided, as tending to break up the flakes of coagulum. Sufficient mixture is generally provided, where the chemicals enter the raw-water main one hundred feet or more from the sedimentation basin, by the agitation due to the flow through the pipe. At some plants especially baffled mixing chambers are provided in connection with the sedimentation basins. Mixture can be obtained across the center of the basin by means of a baffle or submerged weir to contract the area of flow at the point where the chemicals are introduced. After the reaction has taken place, the flow of the water should be as smooth as possible, as the flakes of coagulum are broken up by violent agitation, such as occurs in aerating pipes or weirs.

The lines leading from the orifice box to the point of introducing the chemicals into the water to be treated should be short and as straight as possible. Relatively large-sized pipe should be used to prevent clogging. For lime or soda-ash solutions black wrought-iron pipe is very satisfactory. Galvanized pipe should be avoided. For aluminum or iron sulphate as well as for hypochlorite solutions standard weight lead pipe is fairly efficient. Bronze, rubber, or fiber pipes are sometimes used. It is important that there be no air traps in the coagulant lines. These should, if possible, have a uniform downward grade toward the point of discharge, and near the orifice box should connect into a vent pipe, to allow the air entrapped with the solution to escape.

Comparison of Costs. On Plate IX have been plotted the cost of each of the methods of treatment described, for various amounts of coagulant, and also the cost of removing various amounts of acids. The cost of chemicals includes freight, unloading and cartage, deterioration, and the rehandling in charging the chemical tanks. The costs per hundred pounds used were: aluminum sulphate, $1.10; ferrous sulphate, $0.70; lime, $0.35; soda ash, $1.00. For large-sized plants these values could be reduced. From these curves it is evident that the iron and lime treatment is cheapest, followed by alum and natural alkalinity, alum and lime (sufficient to produce no CO_2), alum and soda ash, while alum and soda ash (no CO_2) is most expensive. It is also evident that by increasing the amount of lime used with the iron, the cost of this process may rise above that of alum and lime. The iron-lime treatment is slightly more effective for high turbidities, a fact not brought out by these curves. For acid removal, lime is by far the cheapest reagent.

Sterilization. While properly treated and filtered water is practically free from bacteria, it has of late years become customary to treat the filtrate with a germicide as an additional precaution. Such treatment should be considered solely as an added safeguard, and under no condition should reliance be placed on it to the extent of neglecting any detail in the process of filtration. Bacterial counts of the filtrate should be made *before* applying the germicide and the plant efficiency based on these. Counts should also be made after sterilization to measure the effectiveness of the agent used.

Hypochlorite of lime has been very extensively used for this

purpose. Liquid chlorine is coming into use. Sodium hypochlorite, electrolytically prepared, and ultra-violet rays have been used experimentally and show promise of future development; ozone and copper sulphate have also been tried.

Hypochlorite of Lime. Hypochlorite of lime ($CaCl_2,Ca(OCl)_2$), known commercially as "chlorid of lime" or "bleach," contains about 70 per cent of a mixed salt (calcium chlorid and calcium hypochlorite), and 30 per cent of impurities, such as lime and water of hydration. It is obtainable in canisters of from 100 to 750 pounds each. If kept exposed to the air, it loses strength through absorption of water and volatilization.

It is soluble in water (about 1 part in 20), separating into its two component salts:

$$CaCl_2,Ca(OCl)_2 = CaCl_2 + Ca(OCl)_2$$

The calcium chlorid is inactive, but the calcium hypochlorite reacts with the free or half-bound carbonic acid in the water, giving hypochlorous acid and calcium carbonate:

$$Ca(OCl)_2 + H_2CO_3 = 2HOCl + CaCO_3$$
$$\text{or } Ca(OCl)_2 + H_2CO_3CaCO_3 = 2HOCl + 2CaCO_3$$

The hypochlorous acid is unstable, and readily gives up its oxygen to organic matter:

$$2HOCl = 2HCl + 2O$$

This oxygen, being in the atomic or nascent state, is very active and is the effective germicide. The hydrochloric acid (HCl) formed reacts with the calcium carbonate ($CaCO_3$) formed in the previous reaction, reverting it into carbonic acid again:

$$CaCO_3 + 2HCl = H_2CO_3 + CaCl_2$$

These reactions and the germicidal effect are also obtained in the absence of carbonic acid, but more slowly. The time required for the completion of the reaction is variable, being, under the best conditions, about 30 minutes, but increasing as the temperature of the water decreases and also being longer in waters containing only half-bound carbonic acid than in those containing free carbonic acid.

Through established (although illogical) commercial usage, the oxidizing strength of the hypochlorite is measured in terms of "available chlorine," that is, the amount of chlorine which be-

comes available on decomposing chlorid of lime with a strong acid. This may be computed when the percentage of pure bleach is known, as follows:

Available chlorine $=0.56\times$ percentage of pure bleach. Thus for the average commercial product containing 68 per cent $CaCl_2,Ca(OCl)_2$ the "available chlorine" is $0.56\times.68=38$ per cent. Only half of the "available chlorine" is liberated by the weak carbonic acid or 0.28 of the pure bleach or "calcium oxychlorid." The actual oxygen liberated is 22.5 per cent of the "available chlorine."

The amount of available chlorine required to sterilize the water varies with the amount of organic matter present and with the turbidity of the water. It is best determined by running bacterial counts on the treated water and using the minimum dose that will insure a practically sterile water. In the absence of bacterial tests or as a check, the "Test for Excess of Hypochlorite of Lime," in Chapter III, may be used. Generally ¼ to ½ part per million of available chlorine is sufficient, although sometimes more is required. This is especially true if the water contains unoxidized organic matter or ferrous salts. In one instance it was necessary to use 2 parts per million of available chlorine, any reduction being followed by an increase in the typhoid-fever rate. Ordinarily so large an amount of hypo would have resulted in a very strong taste in the water, but in this case the water was treated before being delivered to a large impounding reservoir, the prolonged storage reducing the taste considerably. One part per million available chlorine is equal to about 25 pounds of bleach per million gallons. A very common dose is 8 pounds of bleach per million gallons. For treating filtered water 5 pounds is often sufficient.

Hypochlorite exerts a selective action on the bacteria in the water, readily destroying such pathogenic species as B. typhosus, the cholera spirillum, and the like, while the harmless spore-forming varieties are affected to a much less extent.

The chlorid of lime is introduced into the water as a solution in a manner similar to coagulants (see Figs. 10 and 11). As it is not very soluble (about 1 part in 20 of water), a weak solution should be used. This has the further advantages of decreasing the corrosive action on piping and (in the case of small plants) giving a quantity of solution large enough to be accurately mea-

sured by an orifice box of the usual type. For large plants a 2 per cent solution may be used, for smaller plants a 1 or ½ per cent solution is more readily handled. It is often an advantage to make up a stronger "stock" solution, containing about 6 per cent of bleach (approximately 2 per cent "available" chlorine), and dilute this as required to the standard strength.

In making up solutions care should be taken to use sufficient water, as if made into a thick paste the bleach dissolves with difficulty. Use at least ½ gallon of water per pound of bleach. It should also be remembered that a large amount of sludge is formed, and as part of the available chlorine is retained by this an additional allowance must be made. The chlorine in the sludge may be recovered by agitating the sludge in water and using this water in mixing up a fresh batch, although the extra labor and inconvenience involved hardly justify this procedure.

The apparatus used in preparing the solution generally consists of a small mixing or "pasting" tank and two larger solution tanks. The pasting tank is located above the solution tanks (see Fig. 11), and is equipped with horizontal mixing paddles and sometimes with rollers, motor driven, for grinding and mixing the bleaching powder into a paste with water. Two screened overflows are provided near the top of the tank, one to each solution tank, as well as a hose or water connection. The solution tanks are provided with motor-driven stirring paddles and with piping connections to the orifice boxes. These pipes should tap into the tanks somewhat (6 to 9 inches) above the bottom to avoid the sludge that accumulates on the bottom of the tanks. Ample drain pipes should be provided to remove this sludge to a sewer. The tanks are best made of concrete or iron and piping of pure wrought iron (black) or lead. Orifice-box fittings are well made of acid-proof bronze. Wood is readily attacked by the solutions, and if used should be painted with asphaltum or mineral bituminous paint. The same is true of copper or ordinary brass.

The preparation of a solution is best illustrated by a concrete example. Assume that it is desired to treat 5,000,000 gallons per day with 0.4 part per million available chlorine, using 33⅓ per cent bleach (which may be taken as an average value where no analyses are made). Referring to Plate X, and using the dashed line labeled 0.4 part per million available chlorine, it will be seen that 51 pounds of chlorid of lime per day are required. The

dashed line is so drawn as to compensate for the bleach lost in the sludge, using a 1 per cent solution. Assuming a day's supply of 1 per cent solution is to be made up in solution tank No. 1 (No. 2 being in use at the time), weigh out 51 pounds of bleach into the pasting tank, add a small amount of water, and start the mixing paddles. Slowly add water until the tank contains at least ½ gallon for each pound of bleach (or about 25 gallons, preferably somewhat more). Allow the paddles to mix the bleach into a paste (which requires about 15 to 30 minutes), and in the meantime drain tank No. 1 of sludge. Now, with the mixing paddles still in motion, turn a stream of water into the pasting tank so that the solution is slowly flushed into the solution tank through the overflow. Each solution tank should be equipped with a float gage reading directly the number of gallons in the tank. Allow the stream in the pasting tank to continue until the paste is all flushed out and the solution tank contains the amount of water necessary to make a 1 per cent solution. Referring to Plate XI (using the dashed line to allow for loss in sludge), note that 51 pounds of chemical require 620 gallons of water to make a 1 per cent solution.

After the requisite amount of solution has been made up, the stirrer in the solution tank is started and the whole thoroughly and uniformly mixed. The solution is then allowed to settle for at least one hour, and preferably longer, after which a sample is taken off and tested for available chlorine as described in the chapter on chemical tests. If a slight discrepancy is found it is generally sufficient to adjust the orifice opening slightly and correct future solutions accordingly. When tank No. 2 has run out, No. 1 may now be put into service. Care must be taken not to disturb or agitate the solution while the tank is in service, nor must it continue in service after the sludge line near the bottom is reached. By adhering to the instructions here given, tastes in the treated water can be largely avoided.

Plate XI can be used for any chemical solution. In determining the gallons of water for any strength of solution, use the solid lines for clear solutions such as of aluminum or ferrous sulphate, and the dashed lines for solutions which leave a sludge such as lime and hypochlorite. The heavy vertical lines give the amount of solution which will discharge through circular orifices of the sizes noted under 6 inches head in 24 hours. Never use a quantity of solution less than will require an orifice of ⅛ inch

diameter (200 gallons per day), as this is about the practical limitation in size.

The bleach may be applied to the raw, settled, or filtered water. It is least effective applied to the raw water, and is difficult to apply to the filtrate in such a manner as to get uniform distribution, since it must generally be discharged into the individual effluent pipes from the filters into the clear-water basin. Such a distribution is readily obtained by applying it to the water in the latter part of the settling basin by means of a perforated pipe. It may thus be given 15 to 30 minutes for reaction before the water reaches the filters. This has the added advantages that most of the taste caused by the hypochlorite will be removed by adsorptive action in the filters, as well as keeping the filter sand sterilized and preventing "after-growths" of bacteria in the sand and underdrains.

Water which has been treated with hypochlorite very often has an unpleasant taste, suggestive of iodoform. There are several possible reasons for this taste. Probably the action of the hypochlorite on organic matter is partially accountable for it. Since the rate of pumpage varies, whereas the solution of hypo is generally applied uniformly, and since the solution itself may vary in strength, due both to stratification and to variations in the bleaching powder, the water is possibly overdosed at times. If adequate storage is not given after treatment, the water may reach the consumer before the reaction is complete, especially in winter, when it is sluggish.

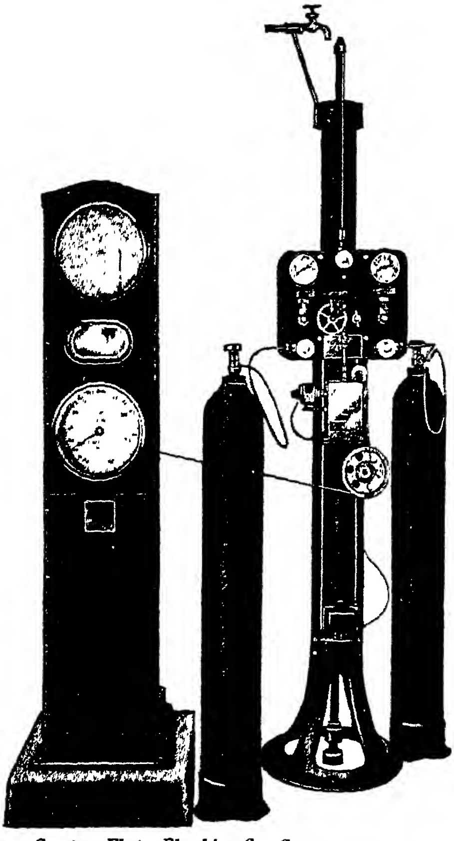
In general, taste may be reduced by automatically proportioning the flow of hypo to the pumpage, by mixing the solutions well to prevent stratification, by tests of the solution to determine the available chlorine, and by storage after treatment sufficient for the reaction to be completed (a minimum of 30 minutes). The taste may be removed chemically by applying sodium thiosulphate ($Na_2S_2O_3, 5H_2O$), in amount half as much as the bleach, 15 to 30 minutes after the bleach has been added. This will remove the taste completely, with no deleterious effect on the water, at an additional cost of about half as much as the bleach. It can be added as a dilute solution by means of a solution tank and orifice box. The addition of the thiosulphate stops the germicidal action of the bleach at once, which is the reason for adding it sufficiently later to allow the bleach to destroy the bacteria.

Liquid Chlorine. Chlorine gas liquefied by pressure has recently found application as a sterilizing reagent. Its germicidal effect results from the same cause as does that of chlorid of lime, namely, the liberation of *nascent oxygen* in solutions. The reactions are as follows:

$$Cl_2 + H_2O = HOCl + HCl$$
$$HOCl = HCl + O$$

The hydrochloric acid formed reacts with the carbonates and bicarbonates in the water to form chlorids and carbonic acid, thus:

$$2HCl + CaCO_3, H_2CO_3 = CaCl_2 + 2H_2CO_3$$



Courtesy Electro-Bleaching Gas Company.

FIG. 76.—Automatic Liquid Chlorine Apparatus.

The reaction is simpler than in the case of chlorid of lime and proceeds readily without the presence of carbonic acid. As the gas is practically pure, and is therefore essentially 100 per cent "available chlorine," only about one-third as much is required by weight as of bleach. Thus, instead of 12 pounds per million gallons of chlorid of lime, 4 pounds of the gas may be used, or instead of 5 pounds (in the case of filtered water), 1⅔ pounds of the gas may be substituted. Efficiency in operation may increase this ratio to 1 to 5 or 6.

The commercial gas is 99.8 per cent pure chlorine and can be purchased in steel cylinders 8 inches in diameter and 60 inches

high containing 100 pounds of chlorine. The pressure in the cylinders varies with the temperature, ranging from 50 to 100 pounds per square inch.

The apparatus used for introducing the chlorine gas into the water takes a variety of forms. One type is shown in Fig. 76. Two cylinders of chlorine gas are connected through a manifold into a single pipe. To this pipe is attached a gage to indicate the initial pressure in the cylinders. The gas is then passed through an automatic pressure-reducing valve which maintains a constant pressure regardless of the decrease in quantity of gas in the cylinders or variations of temperature. The gas then passes through a second adjustable reducing valve by which any desired pressure may be maintained over an orifice plate in the pipe line. The reducing valves perform the same function that the float valve does in an orifice box measuring a chemical solution. The orifice allows a constant quantity of gas to discharge through a pipe into an absorption tower, through which a constant stream of water is flowing. This water absorbs the gas and carries it to the water supply to be treated. A second gage is generally provided to measure the pressure on the orifice. Piping, valves, gages, etc., must be of special design and material to withstand the corrosive action of the gas.

The convenience and simplicity of operation as compared to chlorid of lime are obvious. The annoyance of dust and fumes is done away with, and the floor space occupied is greatly reduced. The cost per pound is about six times that of bleaching powder, but as the strength is about three times as great, and as it can be more effectively applied, the cost of chemical required is less than 2 to 1. Despite this fact, and in view of the decreasing cost of liquid chlorine, it is finding much favor.

Sodium Hypochlorite. Sodium hypochlorite is obtained by passing an electric current through a solution of common salt (sodium chlorid). Its germicidal effect is the same as that of calcium hypochlorite, resulting from the liberation of nascent oxygen. The preparation of it is free from the disagreeable features attending the use of bleaching powder, and there is no lime sludge to dispose of. The process is comparatively new and not well known in the water-works field, and the apparatus is still in the formative stage. With electric current below 1½ cents per kilowatt hour, and salt (second grade) at ⅓ cent a pound or less,

this process should compete on favorable terms with either bleaching powder or liquid chlorine.

The apparatus used is shown in Fig. 77. It consists essentially of a tank for holding salt solution, an orifice box for measuring the solution, and an electrolytic cell. Referring to Fig. 78, it is seen that the cell consists of a soapstone or porcelain box, about 28 inches

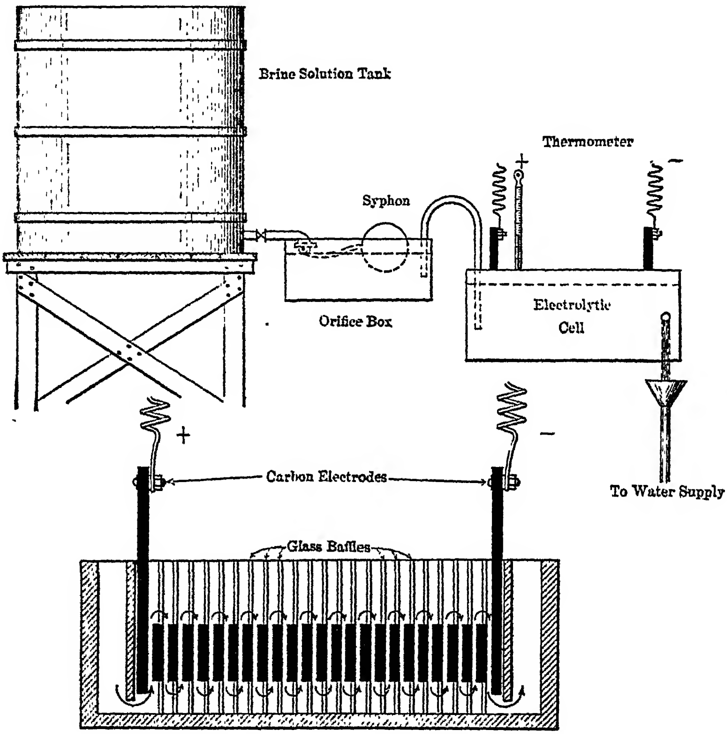


Fig. 77.—Apparatus for Electrolytic Preparation of Sodium Hypochlorite.
Fig. 78.—Electrolytic Cell.

long, 12 inches wide, and 12 inches deep, having at each end a baffle of the same material reaching nearly to the bottom. Between these end baffles are spaced a number of carbon plates (in this case 23), which, together with the glass partitions above and below, divide the cell into 24 compartments. Alternate partitions have the glass baffles perforated with an opening above and below the carbon, so that in passing through the cell the salt solution takes

the circuitous path indicated by the arrows. Current enters and leaves the cell through two carbon electrodes, one at each end. Of the intermediate carbons, one face acts as the positive and the other as the negative pole, so that the whole device is really made up of 24 cells in series.

When a direct current is passed through these cells, and a brine solution is fed into them, sodium is liberated at one pole and chlorine at the other. The sodium combines with the water to form sodium hydroxid and hydrogen. The sodium hydroxid combines with the chlorine to form sodium hypochlorite. The hydrogen gas escapes. The reaction may be represented by the symbols:

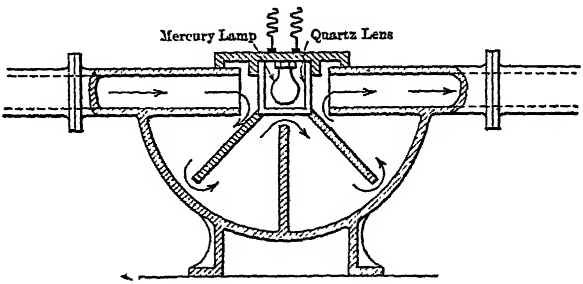
$$NaCl+H_2O=NaOCl+H_2$$

There are, however, several auxiliary reactions which decrease the amount of sodium hypochlorite formed as well as increase the current consumption. Among these are the oxidation of the sodium hypochlorite to sodium chlorate, and its reduction to sodium chlorid by the liberated hydrogen.

Practically, the voltage required is about 4 volts per cell; for instance, the apparatus described above would require a voltage of 24×4, or 96 volts, consequently the ordinary 110-volt current could be used in connection with a rheostat. Theoretically it requires 1.23 kilowatt hours of current and 1.65 pounds of salt to produce 1 pound of available chlorine. However, as the best cells have an energy efficiency of only about 25 per cent, and not more than 20 per cent of the chlorine present as chlorid is converted into hypochlorite, it actually requires at least 5 amperes of current and over 8 pounds of salt per pound of available chlorine.

In practice, the salt is dissolved in water to a strength of about a 10 per cent solution, and is fed gradually to the electrolyzer by means of a siphon connection from the orifice box. The temperature in the electrolyzer should be kept under 100° Fahr. Lower temperatures give better results. The overflow from the electrolyzer is fed into the water to be treated, either directly or through an equalizing tank. The available chlorine in the effluent of the electrolyzer is determined by the test for available chlorine given in Chapter III, and is adjusted by regulating the orifice feed.

Ultra-Violet Rays. The ultra-violet rays from an electric mercury vapor lamp have a direct bactericidal action, not only on bacteria in the active but also in the spore state, which resists vigorous boiling. It is necessary that the lamp be enclosed in a quartz tube, as ordinary glass is opaque to these rays. Also the



Courtesy Scientific American.

Fig. 79.—Ultra-Violet Ray Apparatus.

water must be brought close to the lamp, in order to make the treatment effective, and the rays must be applied after filtration, as any turbidity cuts them off very quickly. The water is run through a cast-iron box, in the top of which is suspended a quartz mercury arc lamp enclosed in a box with quartz sides, to prevent the water striking the lamp, Fig. 79. The cast-iron box is baffled so as to bring the water close to the lamp. An electrically operated valve placed in the line ahead of the apparatus and in series with the lamp serves to by-pass the water in case the lamp becomes inoperative. A series of such apparatus is necessary, as each lamp can only take care of about 150,000 gallons per day. This method has been in use at Marseilles, France, since 1910. It has also been employed in the United States in sterilizing bottled water. Its use in large purification plants has been proposed, and it is probable that, with more efficient apparatus, its application will become practicable where electric current is cheap. It has the advantages of being tasteless and easy of application.

Copper Sulphate. The use of copper sulphate for destroying algæ in reservoirs has been noted in Chapter V. It has also been found that 10 parts per million of copper sulphate will kill typhoid and colon bacilli. Attempts have been made to produce a mixed salt of ferrous and copper sulphates containing about 1 per cent of the latter. Such a coagulant was used with some success at

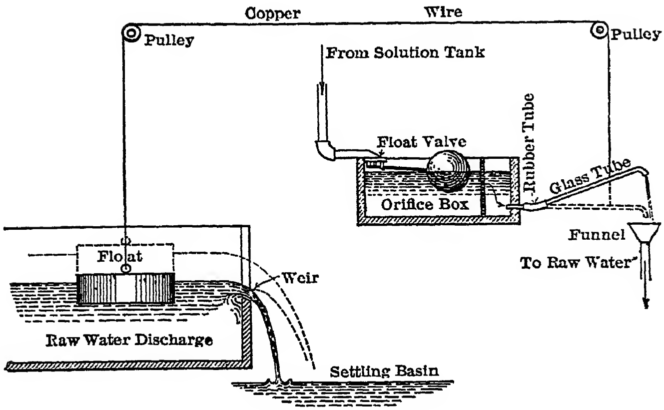
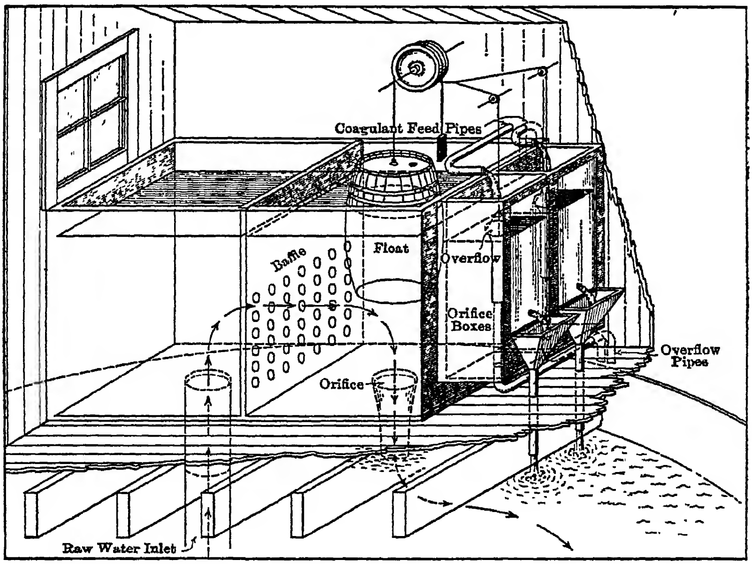


FIG. 80.—Automatic Coagulant Control for a Small Plant.



From "Apparatus for Water Purification Plants," by Thomas Fleming, Jr. Jour. Eng. Soc. Penna., June, 1911.

FIG. 81.—Coagulant Regulating Device at Monessen, Pa.

Marietta, O.,* where a bacterial efficiency of 99.33 per cent was obtained. A small amount of copper was found in the effluent of the filters, attributable to the brass strainers used.

Ozone. Ozone, produced electrolytically, has been used for sterilizing water. Although it has been extensively experimented with for a number of years, it has as yet found very little practical application and seems a less logical successor to chlorid of lime than liquid chlorine, sodium hypochlorite, or ultra-violet rays.

Automatic Regulation of Coagulation. One of the most useful automatic devices with which any plant, large or small, can be equipped is an apparatus for proportioning the amount of coagulant solution to the varying raw-water flow. Any such device involves a means for measuring the raw-water flow and some method of having this affect one of several variables which control the flow of the coagulant solution from the orifice box, namely, the area of orifice opening, or the head over the orifice.

Fig. 80 shows a device of this nature, which has been successfully used in institutional and other small plants. The orifice box is of the standard float-controlled type, being fed from a coagulant solution tank in the usual manner. Instead of an orifice, the outlet from the orifice box consists of a small brass tube nipple to which a glass tube is attached by means of a short piece of rubber hose, making a flexible joint. The glass tube is bent at the end, and discharges into a funnel, whence the coagulant solution flows through a pipe to the raw-water main. The raw water, on its way to the settling basin, flows through a weir box, which is the required measuring device in this case. There is a float in this weir box, and from it a wire or cord runs over pulleys and is attached to the glass tube. When the flow of raw water decreases, the water level in the weir box falls, and the float with it. This exerts a pull on the wire and raises the glass tube, thereby decreasing the flow of coagulant. Similarly with an increased raw-water pumpage the float rises, causing the end of the glass tube to be lowered, thereby increasing the flow of coagulant.

Fig. 81 shows an automatic coagulant regulating device suitable for a larger plant. In this case the apparatus is mounted in a small house directly upon the coagulation basin, which hap-

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* *Engineering Record*, LIII, p. 392.

pens to be a large round steel tank. The raw water is pumped through the inlet pipe into a large box. In this it flows through a perforated baffle and out through an orifice in the bottom of the box. The coagulant orifice boxes are attached directly to the raw-water orifice box, and are of rather deep proportion with glass fronts. The coagulant solution is pumped from solution tanks below up into the orifice boxes which are provided with overflows, the surplus pumpage overflowing and running back into the solution tanks by gravity. These overflows have a telescoping joint and are hung from cords passing over differential pulleys and leading to a barrel float in the raw-water orifice box. An increase in pumpage causes the water level in the raw-water orifice box to

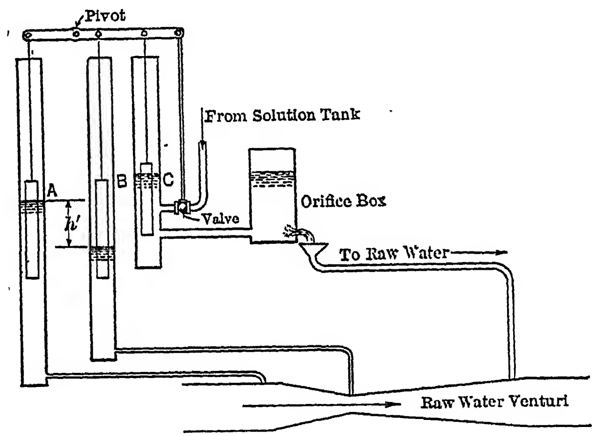
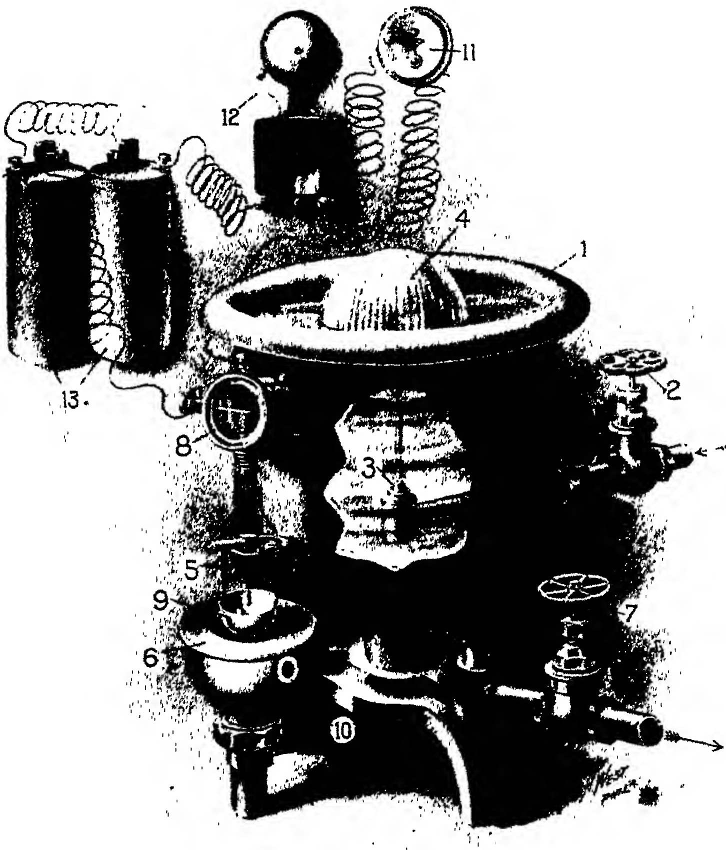


FIG. 82.—Coagulant Controller for a Large Plant.

rise, carrying the barrel float up with it. This, acting through the counterweight and differential pulley, raises the overflow funnels, and consequently the water level in the coagulant orifice boxes, increasing the flow of coagulant solution.

Fig. 82 shows diagrammatically the principle of one of several patented devices used in large filtration plants. The raw water is measured by means of a Venturi meter or other constriction in the pipe. The water levels at the inlet and at the throat of the tube are carried to the float tubes A and B. Due to the increased velocity of the water through the throat, the water level in tube B is lower than that in tube A by a distance h', which increases as the

flow through the meter increases. It is evident that under action of the floats A and B alone the pivoted walking beam would be tilted downward at the right-hand end. This causes the valve in



Courtesy of the Roberts Filter Manufacturing Co.

FIG. 83.—Constant Feed Orifice Box.

the line from the solution tank to the float tube C to open, admitting coagulant solution until the upward force due to the submergence of float C is sufficient to bring the walking beam level. This closes the valve in the coagulant line. The water

level in tube C is communicated to the orifice box, the discharge of which varies with this water level.

Fig. 83 shows an orifice box designed for use where the raw-water pumpage is constant, which combines a number of useful features. It consists of an enameled iron tank (1), containing a float valve (3), fed from the coagulant solution tank through the pipe and valve (2). The water level in the tank is maintained at a constant height by the glass float (4). The orifice is an adjustable needle valve (5). The discharged solution falls into a perforated cup (9), and from this into the funnel (6), which connects to a pipe leading to the raw water. It will be noted that the cup (9) is suspended from a spring. Any variation in the orifice discharge, due either to the clogging of the orifice or to the failure of the float valve to operate properly, causes the weight of this cup to vary, thereby extending or contracting the spring and closing the electrical contact (8). This causes the bell (12) to ring, warning the operator that the orifice box is not acting properly. The bell may be shut off by opening the switch (11) when the orifice box is not in use. A drain (7) is provided, as well as a flushing connection (10), to which a pressure pipe may be attached for cleaning out the coagulant discharge line.

There are numerous other methods of accomplishing the same results. all based on the principles above outlined.

CHAPTER VII

WATER-SOFTENING

It is sometimes desirable to soften a water as well as filter it, and for this purpose the mechanical filter plant is well adapted with a few modifications. Essentially these modifications consist of:

a. Larger sedimentation basins.

b. Facilities for mixing the lime with the water.

c. Increased facilities for handling lime and soda ash.

Larger sedimentation capacity is necessary to allow sufficient time for the reaction between the lime and the bicarbonates in the water, thereby avoiding to a large extent deposits of calcium carbonate on the grains of the filter sand, and in the filter piping and mains. The time for the reaction depends on the constituents in the water, on the adequacy of mixing the lime with the water, on the design and condition of the basins, and on the temperature. A sedimentation period of from 10 to 12 hours fulfils average conditions, although at times a period of 4 hours may be sufficient. These periods are based on the total capacity of the basins. Water containing large amounts of magnesium salts requires a longer period for reaction. Generally the same is true of attempts to soften waters which are not very hard to begin with.

The thorough mixture of the slaked lime with the water is extremely important. This may be accomplished in several ways. The lime emulsion may be added to the raw water shortly before it reaches the mixing chamber. It should be introduced into the raw-water main through several pipes entering at points a number of feet apart, since the lime emulsion is not very soluble, and if introduced at one point would sink to the bottom of the main and badly choke same. The mixing chamber in this case is divided by vertical baffles into compartments about 3 feet wide, causing the water to travel up over one baffle and down under the next at about 1 foot per second velocity. By providing mixing chambers of this type of half an hour's capacity, a very thorough mixture of the lime emulsion and the water is obtained, and the softening

reactions are greatly accelerated. Another method of accomplishing the same result is that described in connection with the Columbus filtration plant (Chapter II). There the raw water is divided into three parts. Twenty-five per cent of it is led to a number of saturation chambers, where the total dosage of lime is added to it, and it is thoroughly mixed by means of revolving paddles. Another 25 per cent is dosed with soda ash in another compartment. These two portions are then returned to the remaining 50 per cent of untreated water, and the whole is run through a mixing chamber of the type already described.

The sedimentation basins, besides being of the capacity above stated, should be so designed as to give the water a velocity of from 2.5 to 3.0 feet per minute. They should be well baffled, so as to prevent shortcircuiting of the water. There seems to be some advantage in having a small amount of sludge present in such a manner that the water passing through comes in contact with it, as this seems to promote precipitation of the carbonates.

With water at a low temperature a longer sedimentation period is required than with a warmer water, this following from the laws of chemical reaction.

The need for larger lime and soda tanks, pipes, conveyers, and storage facilities is evident, in that from five to ten times as much of these chemicals must be handled as in ordinary filtration. Methods of dry feeding such as were described in connection with the Columbus plant become almost imperative in the larger installations.

The meaning of the term "hardness," the constituents producing this quality, and the properties imparted by their presence to the water, have been discussed in the chapter on the "Interpretation of Tests." The chemical constituents causing this quality may be recapitulated in another manner, as shown on following page.

The bicarbonates of calcium, magnesium, and iron constitute temporary hardness, being removed by boiling or precipitated by lime. The sulphates, chlorids, and nitrates (together with a small residue of the normal carbonates) of calcium and magnesium cause permanent hardness, not being removed by boiling, but being precipitated as calcium and magnesium* carbonate upon the

* Magnesium carbonate is somewhat soluble, but is precipitated by additional lime.

Hardness	Alkalinity	Bicarbonates of	Calcium (Ca) Magnesium (Mg) Iron (Fe)
		Carbonates of	Calcium Magnesium
		Hydroxids of	Calcium Magnesium
	Incrustants	Sulphates Chlorids Nitrates of	Calcium Magnesium
	Mineral acidity	Sulphuric acid	
		Sulphates of	Iron (Fe) Aluminum (Al)

addition of soda ash. Bicarbonate of iron occurs in some waters, and may be considered as temporary hardness.

The question of the degree of hardness permissible is one of locality to a large extent. A central State water which passes without comment would seem extremely hard to a visitor from New England. Considering the economic aspect of the question as regards soap consumption and the formation of boiler scale in addition to the personal equation, it would seem that softening may be regarded as unnecessary with water of a temporary hardness from 75 to 100 parts per million or less, the exact value depending somewhat on the additional permanent hardness present. The value of permanent hardness at which softening may rationally be considered is approximately 50 parts per million. In other words, the question of water-softening may be profitably contemplated when the total (temporary + permanent) hardness of a water reaches 150 parts per million. On the other hand, it is necessary to neutralize mineral-acid hardness, even when present only in small amount, owing to its corrosive action. A few rivers receiving much mine drainage have a mineral acidity of over 20 parts per million.

There is a lower limit beyond which softening should not be attempted. This may be placed at from 50 to 60 parts per million. Due to limitations in the accuracy of applying the lime and soda solutions, and vagaries in the reactions of softening, attempts to work to a lower limit would result in caustic water at times, and this would lead to trouble with after-precipitation, and

to complaints from the consumers, due to the greater hardness of the caustic water, and to its objectionable taste. Small plants, where regulation is not very efficient, had better limit themselves to a total hardness of 75 in the effluent. It is questionable whether extremely soft waters, even when naturally so, are as healthful as waters containing more natural salts in solution (especially calcium salts). Investigations seem to show that in regions with fairly hard waters, the inhabitants are larger and less susceptible to dental and bone diseases.* Researches made by Messrs. Olaf Bergem and P. B. Hawk, University of Illinois, seem to show that water rendered caustic by lime treatment has an inhibitive action on the digestive processes. This applied particularly to water containing magnesium hydroxid after treatment, and was attributed to the adsorptive action of this substance in colloidal form on the saliva. This action is stronger the more recently the water has been softened.

Reactions of Water-Softening. The reactions between the lime and the bicarbonates in the water are as follows:

1. $CO_2+Ca(OH)_2 = CaCO_3+H_2O$
2. $CaCO_3H_2CO_3+Ca(OH)_2 = 2CaCO_3+H_2O$
3. $2NaHCO_3+Ca(OH)_2 = CaCO_3+Na_2CO_3+2H_2O$
4. $MgCO_3H_2CO_3+2Ca(OH)_2 = 2CaCO_3+Mg(OH)_2+2H_2O$

The lime seems to attack the constituents of the water in the order given. First the free carbonic acid is removed, then respectively the bicarbonates of calcium, sodium, and magnesium. Note that twice as much lime is used for precipitating the bicarbonate of magnesium, as the carbonate is soluble and must be converted into the insoluble hydroxid. The precipitated calcium carbonate is somewhat soluble (about 30 p.p.m.), so that it is impossible (as well as undesirable) to remove hardness entirely.

The removal of permanent hardness is accomplished by the following reactions for calcium salts:

$$\left.\begin{matrix} CaSO_4 \\ CaCl_2 \\ Ca(NO_3)_2 \end{matrix}\right\} + Na_2CO_3 = \left\{\begin{matrix} Na_2SO_4 \\ 2NaCl \\ 2NaNO_3 \end{matrix}\right\} + CaCO_3$$

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* Berg, *Biochemische Zeitschrift*, v. 24, p. 282 (1910); v. 26, p. 204 (1910). Rose, *Deutsche Monatschrift f. Zahnheilkunde*, 1904–1908.

The similar reactions for magnesium salts are:

$$\left.\begin{matrix} MgSO_4 \\ MgCl_2 \\ Mg(NO_3)_2 \end{matrix}\right\} + Na_2CO_3 + Ca(OH)_2 = \left\{\begin{matrix} Na_2SO_4 \\ 2NaCl \\ 2NaNO_3 \end{matrix}\right\} + CaCO_3 + Mg(OH)_2$$

In neutralizing acid water the reactions are:

$$H_2SO_4 + Na_2CO_3 + Ca(OH)_2 = Na_2SO_4 + CaCO_3 + 2H_2O$$

$$FeSO_4 + Na_2CO_3 + Ca(OH)_2 = Na_2SO_4 + CaCO_3 + Fe(OH)_2$$

The sodium carbonate is added to remove the calcium sulphate formed by the reaction of the acid or sulphate with the calcium hydroxid.

Special Tests in Water-Softening. The necessary tests to determine the amounts of lime and soda ash required in water-softening are:

1. Free carbonic acid.
2. Half-bound carbonic acid (44 per cent of the bicarbonates).
3. Total magnesium.
4. Incrustants.

The tests for free carbonic acid and bicarbonates were given in detail in the chapter on tests. The tests for magnesium and incrustants follow.

Total Magnesium:* Apparatus. Six-inch porcelain dish, one 25-cc. pipette, one 150-cc. measuring flask, Bunsen burner.

Reagents. $\frac{n}{50}$ sulphuric acid, a clear, saturated solution of lime-water, erythrosin, and phenolphthalein.

Procedure. The solution of lime-water is made by adding pure calcium oxid to boiled distilled water in quantity sufficient to leave a residue of undissolved lime after vigorous shaking. Allow the solution to stand until all undissolved lime has settled out. Test the strength of the lime-water by carefully measuring out 25 cc. and titrating with $\frac{n}{50}$ sulphuric acid using phenolphthalein. Determine the alkalinity to erythrosin of a sample of the water to be tested. Take another 100-cc. sample of the water and pour into a 6-inch porcelain dish. Add the same amount of $\frac{n}{50}$ sulphuric acid as was used in the alkalinity test, which should make it neutral to erythrosin. Boil down to a volume of 30 to 40 cc. to expel the free, half-bound, and bound carbonic acid.

Introduce 25 cc. of clear saturated solution of the lime-water into a 150-cc. measuring flask, glass-stoppered. While still hot,

* "Standard Methods of Water Analysis." A. P. H. Assoc.

transfer the contents of the porcelain dish to this flask, and rinse the dish several times with hot distilled water, pouring the rinsings into the flask, and make up the solution to about 2 cc. above the 150-cc. line in the flask. Mix well, stopper immediately, and cool until the precipitated magnesium hydrate has completely settled out. Pipette off 50 cc. of the clear solution, using care not to disturb the precipitate, and run into a porcelain dish. Titrate with $\frac{n}{50}$ sulphuric acid to phenolphthalein until neutral.

If C represents the number of cc. of $\frac{n}{50}$ sulphuric acid required to neutralize 25 cc. of the lime-water, and N the number of cc. of the same acid used in the final titration, then the magnesium (Mg) in parts per million equals 2.4 (C–3N).

Incrustants.* Under this name are included the sulphates, chlorids, and nitrates of lime and magnesium which cause permanent hardness.

Apparatus. 500-cc. Jena glass Erlenmeyer flask, 200-cc. graduated flask, 100-cc. measuring glass, glass filter funnel and filter paper, Bunsen burner.

Reagents. $\frac{n}{10}$ soda reagent (equal parts $NaOH$ and Na_2CO_3), $\frac{n}{20}$ sulphuric acid, erythrosin, boiled distilled water.

Procedure. Measure 200 cc. of the water into the Jena glass flask; boil 10 minutes to expel the carbonic acid and add 25 cc. of the soda reagent. Boil down to 100 cc., cool, rinse into 200 cc. graduated flask, and make up to 200 cc. with boiled distilled water. Filter, rejecting the first 50 cc. and titrate 100 cc. of the filtrate, using $\frac{n}{20}$ sulphuric acid and erythrosin. Take 25 cc. of the soda reagent and titrate with $\frac{n}{20}$ sulphuric acid and erythrosin. If S = the cc.'s of $\frac{n}{20}$ sulphuric acid (H_2SO_4) required to neutralize 25 cc. of soda reagent, and N = cubic centimeters of $\frac{n}{20}$ sulphuric acid (H_2SO_4) required to neutralize the 100-cubic-centimeter sample of the filtrate, the incrustants in parts per million (as calcium carbonate) equal 12.5 (S–2N).

Treatment. From the above reactions it will be seen that in order to remove the temporary hardness, it is necessary to add enough lime to react with the carbonic acid, the bicarbonates, and an additional amount for the magnesium salts, so that they may be precipitated as magnesium hydroxid. Sodium bicarbonate (Equation 3), while not causing hardness, must be removed, if

* "Standard Methods of Water Analysis." A. P. H. Assoc.

present, before the magnesium compounds will be attacked. The amounts of 85-per-cent lime required for this purpose are:

10 parts per million of:	*Require 85 per cent CaO in pounds per million gallons:*
Free and half-bound CO_2	125 pounds
Magnesium (total)	224 pounds

The amount of 97-per-cent soda ash required to remove the incrustants is:

10 parts per million of:	*Require 97 per cent Na_2CO_3 in pounds per million gallons:*
Incrustants as $CaCO_3$	91 pounds

In neutralizing acid hardness (measured as H_2SO_4), use the following amounts:

10 parts per million of:	*Require per million gallons:*
H_2SO_4 (disregarding formation of $CaSO_4$)	56 pounds 85 per cent CaO
To remove incrustants ($CaSO_4$) formed	94 pounds 97 per cent Na_2CO_3

Example 1. A typical "hard" water analyzing:

Turbidity,	150 parts per million
Free CO_2,	10 parts per million
Erythrosin alkalinity,	150 parts per million
Phenolphthalein alkalinity,	0 part per million
Incrustants,	95 parts per million
Magnesium,	21 parts per million

Referring to Plate II, it is seen that all the alkalinity is in the form of bicarbonates. The half-bound CO_2 therefore is 44 per cent of 150 or 66 p.p.m. The alum required is found from Plate III, using the medium curve, to be 1 grain per gallon, or 143 pounds per million gallons. Referring to Plate IV, the amount of lime required for no increase in CO_2 is .35 grain per gallon, or 50 pounds per million gallons. The combined (free and half-bound) CO_2 is $10+66=76$ parts per million.

The amount of lime required is:

To react with alum	50 pounds per million gallons
For free and half-bound CO_2— 7.6×125	950 pounds per million gallons
For total magnesium—2.1×224	470 pounds per million gallons
Total lime (85 per cent CaO)	$=$ 1,470 pounds per million gallons

The amount of soda ash required is:
To react with incrustants—

9.5×91	=	865 pounds per million gallons

Example 2. A typical acid-water analyzing:

Turbidity,	10	parts per million
Free CO_2,	10	parts per million
H_2SO_4 acidity,	22	parts per million
Iron,	1.5	parts per million
Incrustants,	81.4	parts per million
Magnesium,	6.7	parts per million

From Plate VI, a turbidity of 10 requires 0.4 grain per gallon of ferrous sulphate. Referring to Plate VIII, it will be seen that the iron present together with some of the acidity is just sufficient to supply the coagulation required, so that no ferrous sulphate need be added.

The lime required is:

For free CO_2,	$1 \times 125 =$	125 pounds per million gallons
For H_2SO_4 acidity,	$2.2 \times 56 =$	124 pounds per million gallons
For total magnesium,	$0.67 \times 224 =$	150 pounds per million gallons
Total lime (85 per cent CaO),		399 pounds per million gallons

The soda ash required is:

For H_2SO_4, acidity,	$2.2 \times 94 =$	207 pounds per million gallons
For incrustants,	$8.14 \times 91 =$	741 pounds per million gallons
Total soda ash (97 per cent),		948 pounds per million gallons

In these examples sufficient soda and lime have been added to react with all the hardening constituents of the water. This is not always desirable, as under many conditions it is more economical to remove only part of these. For instance, if the water contains a large amount of bicarbonates of calcium and sodium and a relatively unimportant quantity of magnesium salts, the last could not be removed until all the calcium and sodium bicarbonates had been precipitated. This would mean that much of the lime would be required to remove the sodium bicarbonate, which is not objectionable. In such a case it might be more economical to add only enough lime to react with the bicarbonate of calcium.

To determine the most economical treatment, test the raw water for free and half-bound carbonic acid, incrustants, and magnesium, and compute the amounts of lime and soda ash needed

for their complete removal. Then take ten half-gallon bottles, each containing a quart of the raw water, and add proportions of lime and soda from one-tenth to the full amount required for complete removal of hardening constituents. Shake well, and allow to stand for 24 hours. Then analyze the contents of each bottle for alkalinity and incrustants to determine the reduction in hardness. In this way determine the proportions and amounts, giving a maximum reduction with the use of a minimum of chemicals.

Introduction of Coagulants. The point of introduction of the coagulants (aluminum or iron sulphate) deserves special consideration in water-softening. During the progress of the softening reaction, the final products, calcium carbonate and magnesium hydroxid, are present in the water in quantities above the saturation value. This follows because the water is always in contact with precipitated calcium carbonate and magnesium hydroxid, and because of the tendency of these substances to form through the reaction of the slaked lime and bicarbonates present in the water. The result is that the water is a supersaturated solution of these compounds, and furthermore contains them in a finely divided state of incipient precipitation akin to a colloidal solution, which gives to the water what may be called an artificial turbidity. Anything which will destroy this condition of unstable equilibrium and hasten precipitation will materially shorten the reaction period of the softening process. Passing the water over cakes of calcium carbonate or violently agitating the water (especially in contact with sand) are two methods of bringing this about. Better than either is the addition of a coagulant. It is found that one grain of aluminum sulphate will reduce the alkalinity of lime-treated water 30 parts per million, instead of 7 to 8, as the theoretical reaction would indicate. This action is mechanical as well as chemical. It is therefore advisable to add some coagulant to the treated water as it leaves the mixing chamber. It sometimes happens that the water becomes quite clear in the settling basins before it reaches the filters. In that case, a small amount of coagulant should be added to the water as it leaves the settling basins, in order that there may be sufficient precipitate in the water to form a good mat on the filters. It may be added that magnesium hydroxid itself is a flocculent precipitate and acts as a coagulant at times.

CHAPTER VIII

SEDIMENTATION

THE purposes of sedimentation are: *a*, to allow the suspended and coagulated matter to settle out of the water; *b* to allow time for the complete reactions of the coagulating chemicals; *c*, by (*a*) and (*b*), to relieve the filters of a large amount of work (at least 80 per cent), and to reduce the washing of the filters to a minimum; *d*, to act as an equalizing basin for the raw-water pumpage, thereby keeping the load on the filters uniform.

The time required for the settling out of the suspended matter is a variable quantity, depending chiefly on the size and specific gravity of the suspended particles. To a less extent it is affected by the nature of the particles, by the temperature of the water, and by its chemical constituents. Where sedimentation is preliminary to filtration a period of 2 to 6 hours is generally allowed. Where coagulation and sedimentation constitute the final process the period should be from one to three days.

The time for completion of reactions varies with the chemicals used, their concentration, thoroughness of mixing, and the natural qualities and temperature of the water. Alum and iron reactions are quite rapid, rarely requiring more than 30 minutes, but the reaction of lime with the bicarbonates of the water is slow, and may require 12 hours.

With very turbid water the sedimentation is advantageously divided into two stages: *a*, Plain sedimentation, to remove the heavy suspended matter; *b*, coagulation and sedimentation, to remove the lighter suspended and colloidal matter. This point and the application of the chemicals have been more fully considered in the chapter on Coagulation and Sterilization.

Much importance attaches to the proper baffling of a sedimentation basin, in order to prevent the water from following currents or short-cutting. It sometimes happens that through improper baffling a basin designed to give four hours' sedimentation is in reality allowing the water to pass through in half an hour. The raw water, being drawn from near the bottom of a river or

lake, is always of maximum density. Assuming an unbaffled basin or one of type shown in Fig. 84, and that it has been standing full of water preliminary to starting, so that the water has been warmed or cooled, according to season, in either case decreasing

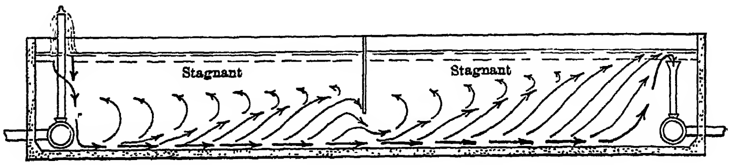


Fig. 84.

its specific gravity, the raw water pumped into it on starting will sink and flow along the bottom of the basin, due to its greater density. This tendency to sink to the bottom of the basin is

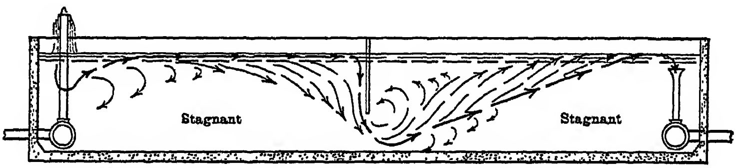


Fig. 85.

increased where the water enters the basin by means of aerators, as in Fig. 84, due to the downward velocity imparted thereby. The water flowing along the bottom causes an upward displacement of the lighter water in the basin and starts a current near the surface toward the outlet. With no baffle in the basin the lighter water would gradually be removed and a more uniform flow result, but with the very common central baffle, the water would form the currents shown, the heavier lines representing the most rapid flow, and a large portion of the basin would be ineffective. With warmer ground water the flow would be as in Fig. 85. This is not as bad, as the quiescent water below receives the sediment

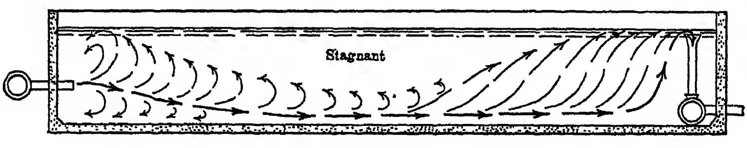


Fig. 86.

from the flowing stratum and allows it to settle, whereas in Fig. 84 the water tends to scour the sediment from the bottom and carry it to the filters to a greater extent.

The persistence of currents once formed is very marked, even after the difference in specific gravity or the initial velocity causing them is removed. Thus the currents, formed in types of Figs. 84

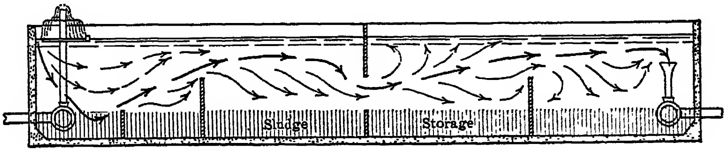


Fig. 87.

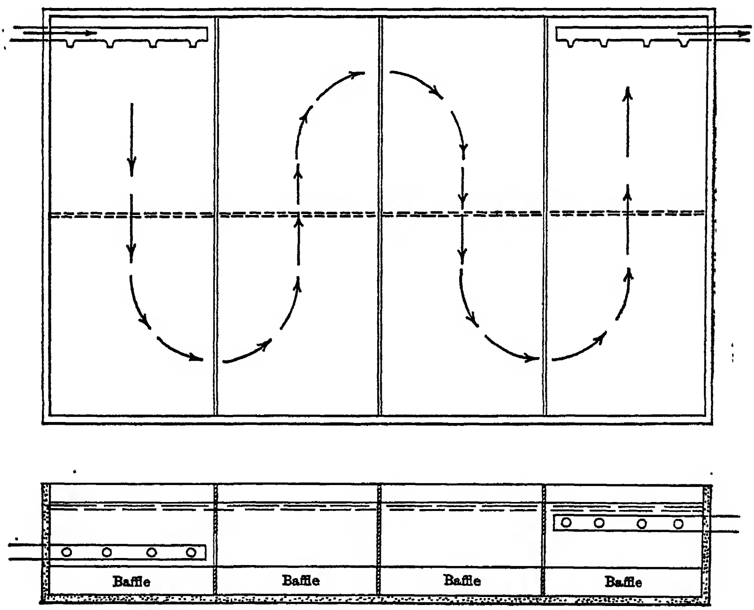


Fig. 88.

and 85, continue after the temperature of the water is equalized throughout, as determined by a delicate thermometer. This persistence is also shown in Fig. 86, showing the very common manner of introducing the raw water into the settling basin by one or more horizontal pipes. Eddy currents are set up thereby, as

shown. The introduction and withdrawal of the water should be done with as little agitation or velocity as possible, either by weirs, or grids of pipe with numerous openings.

Fig. 87 shows a satisfactory arrangement of baffles for a small rectangular basin with aerator inlets. A splasher float is provided below the aerators to break the fall of the water. The baffles at the quarter points prevent under-scour, and the central baffle breaks up surface currents. The lower four feet act as a receiving basin for sediment settling out of the water above.

Fig. 88 shows a system of vertical baffles adapted for large basins.

Every effort should be made to get the most work out of the basin, by proper coagulation, baffling, and cleaning, as in this way the expense of operating and washing the filters is reduced. Occasional bacterial and turbidity tests of the influent and effluent should be made, to determine the efficiency of sedimentation. A properly operated basin should effect a removal of bacteria and sediment of from 75 to 90 per cent. The efficiency depends on the area and depth of the basin, as well as upon the turbidity and amount of coagulation in the water. With the copious precipitates obtained in water-softening, in conjunction with the large sedimentation basins used, it is possible to get an average bacterial removal of 98 per cent. The effluent from the basins should not be entirely clear, but should have a visible coagulation corresponding to a turbidity of from 25 to 35.

To obtain the best efficiency, the basins must be cleaned as frequently as conditions require. Generally the time for cleaning is indicated by a decrease in basin efficiency, due to some of the settled silt and coagulant being swept up from the bottom and carried over to the filters. In deep basins septic action may start, evidenced on the surface by the appearance of gas bubbles or pieces of black sludge. In warm climates the formation of algæ, slimes, or vegetative growths on the surface makes very frequent cleaning necessary.

To clean a basin, it should be drained, and the accumulated sludge swept or flushed with a fire hose into the sewer.

CHAPTER IX

FILTRATION AND GENERAL OPERATION

Routine of Operation. To operate a filter plant efficiently, certain recurring portions of the work should follow a definite schedule. The operations which can generally be so arranged are:

a. Making of tests.
b. Preparation of coagulant solutions.
c. Inspections of plant.
d. Washing of filters.

The basis of the routine should be the length of time during which the men work, which is usually 8 or 12 hours, but may be a variable quantity in the case of small plants, which are shut down daily after pumping a certain required quantity of water.

Making of Tests. In plants which operate only a portion of the day the tests are generally made before starting up in the morning, and in some cases only the physical and chemical tests are run, and weekly samples are taken and sent to a competent bacteriologist for determination of the bacterial count and coli in the effluent. A more rational procedure would be to take the raw-water samples before starting, the settled-water samples (at the outlet of the basins) after an interval equal to the actual time required for the water to pass through the basins (determined as described under Calibration), and the filtered-water samples (from the effluent sample pumps) after an interval equal to the actual time required for the water to pass through the filters and connecting piping.

In plants running continuously samples are generally taken and tests made sufficiently before the end of a shift so that the results may be available for making up the solutions for the coming shift. With variable raw-water conditions it may become necessary to make tests at four- or even two-hour intervals, but this is exceptional. In all cases there is an advantage in allowing a proper time interval to elapse between the taking of raw-, settled-, and filtered-water samples, so that the same " batch " of water may be followed through the whole process.

The dosage, chemical and physical constitution of the water are

continually fluctuating about a mean value, which is itself varying in a more uniform manner, so that the samples taken at even two-hourly periods will probably depart considerably from average conditions. In large plants where economic conditions warrant the effort, it may be well to take samples half-hourly for limited periods, so as to get composite results. A series of tests taken close together, two or three times a year, and carefully studied will often point to possible improvements in the methods of applying chemicals and the coagulation process generally.

Preparation of Coagulant Solutions. From the tests and with the aid of the charts explained in the chapter on Coagulation, it is possible to compute the pounds of coagulant required per million gallons. It still remains to ascertain the number of million gallons to be pumped. If the plant is not equipped with automatic coagulant regulation, the engineer should be required to inform the filter operator as to the rate at which he intends to pump during the coming shift of 8 or 12 hours, and to maintain this rate of pumping uniformly. If a departure from the fixed rate becomes necessary during the shift, the pumping-station engineer should be obliged to notify the filter-plant operator, so that the latter can make the necessary adjustment of orifice boxes, etc. This calls for means of measuring the rate of pumpage. With direct-acting pumps this is most readily accomplished by means of stroke counters; with centrifugal pumps, by means of speed counters or tachometers. If either of these methods is used, the pumps should be recalibrated frequently, as explained under Calibration. Devices for the same purpose, which are less liable to variation, are Venturi meters, pitometers, weirs, and orifices. If possible, a permanent measuring device of one of these types should be installed in the raw-water line, with indicators in both the coagulant house and pumping station.

The amounts of chemicals, as determined from the tests and pumpage, are carefully weighed out upon a platform scale, a separate weighing box being maintained for each kind of chemical. In large plants, where conveyers and other labor-saving apparatus are used, automatic hopper or other special scales are often provided for the chemicals.

The most troublesome and wasteful chemical that must be handled is quicklime. It requires considerable labor in slaking, and the emulsion clogs pipes and is particularly troublesome in

the orifice boxes, much lime tending to settle out, due to the small flow through the orifice. The losses result principally through carbonization in storage, incomplete slaking, and the settling out of the hydrate when applied as an emulsion to the raw water, due to its small solubility (only the portion in solution takes any part in the reaction with the alum or iron). This loss may amount to from 25 to 50 per cent. To reduce losses to a minimum, it is necessary to secure high calcium lime and have it shipped to the plant, where small amounts are used, in tight barrels; where large amounts are used, in bulk, in tight box cars, with all openings carefully closed, to prevent the entrance of air or moisture. Arriving at the plant, if in barrels, it should be stored in a dry place; if in bulk, in covered concrete bins, having a hopper bottom, so that it may be withdrawn from underneath without the admission of air. It should then be weighed out as required, and slaked in an iron slaking box, using about three times its volume of hot water. The lime should be mixed with the water until every part is moistened, but should not be stirred while slaking. Covering the box to conserve the heat is advantageous. Two slaking boxes and two solution tanks should be used, so as to allow a batch to be slaked during the previous shift. The slaked lime should be run through a strainer screen into the solution tank and diluted with water to an emulsion of the consistency of milk. To keep a uniform concentration, the stirring paddles must be kept in constant motion while the solution is being used. The connection from the solution tank to the orifice box should be as short and straight as possible, as it is here that the greatest constriction must necessarily occur. The orifice box should receive frequent attention, to see that the lime does not settle therein and the orifice does not clog. The discharge line from the orifice box to the raw water should be as short and straight as possible. The strength of solution should be kept constant, and changes in treatment made by increasing or decreasing the orifice opening. Thus, with a sliding orifice, assuming that approximately 2 grains per gallon of lime are to be used, slake the proper amount, and dilute with enough water to make an amount of emulsion that will last just one shift (8 to 12 hours), with the orifice at a mid-position. Then if, owing to a change in the raw water, 4 grains per gallon are required, open the orifice twice as wide; if 1 grain is required, close the orifice to half the initial width.

Alum, iron sulphate, and soda ash should be dissolved in warm water and discharged into the respective solution tanks through strainer screens. The solutions should have a strength of not over 6 per cent. The stirring paddles need only be run until the concentration of the solutions has become uniform. To prevent oxidation of the iron solution, the tank should be covered and stirring reduced to a minimum. The predetermined amounts of coagulant should be used in making up solutions, and the amount of water necessary to dilute to the customary strength added. Then the orifice should be set to pass this amount of solution in 8 or 12 hours, as the case may be. Any sudden variation can be met by opening or closing the orifice proportionately. The number of gallons of water required to make a 6 per cent solution is two times the pounds of coagulant; for a 3 per cent solution, 4 times the pounds of coagulant.

Besides keeping the solutions of uniform strength, it is essential that the orifice boxes operate properly. This involves keeping a constant head over the orifices and keeping the orifices open to full size. Small particles of sediment or coagulant lodging in the seat of the float valve may prevent this from closing and result in an increase in head over the orifice. Coagulant may lodge or crystallize on the edges of the orifice and especially in the corners and cause a marked variation in flow.

Hypochlorite of lime is relatively insoluble, and its resistance to solution is increased by the fact that it tends to float on top of the water. It is customary to mix the required amount in a small tub provided with a revolving paddle, so that it can be brought into intimate contact with the water, and then empty this solution into a larger tank, where it is diluted with water to about a 2 per cent solution. The fumes from the dry hypo are very corrossive, especially to copper and brass, and it is well to have as little as possible exposed to the air. The orifice box should be made with as little brasswork as possible, hard rubber forming a good substitute.

Duplication of tanks, orifice boxes, and piping is very essential in this part of the plant, as with a breakdown in chemical treatment a satisfactory effluent is not possible.

Regarding the storage of chemicals, that of lime has been considered. The remaining should be stored in a dry place convenient of access.

Ferrous sulphate, on exposure to air and moisture, oxidizes on the surface, with the formation of ferric sulphate and hydroxid. Therefore it should be stored in bins with a minimum exposure of surface.

Inspection. Hourly inspections should be made of the orifice boxes, to insure their feeding the coägulant regularly, and to guard against stoppage. The solution tanks should be looked after frequently, to see that the mixing paddles are in operation and the solution is of uniform strength.

The same may be said with regard to examining the coagulation of the raw water at the inlet to the settling basin and on the filters. This is best done by collecting a sample of the water in a clean, clear glass. The coagulation should be plainly visible, of about half a pin-head in size, and flocculent. The settled water should show a visible coagulation corresponding to a turbidity of about 25 to 35. Should it be excessively turbid, if aluminum sulphate is being used alone, increase the dose or add about one-third as much lime; with a very turbid water, try applying part of the coagulant at the center of the basin. The excessive turbidity of the settled water may also be caused by sediment being swept up from the bottom of the settling basin, if it is not clean.

Acid waters or those containing ammonia, organic matter, or alkalis in certain concentration give trouble with colloidal solutions of the coagulant, especially in cold weather. Decreasing the ratio of lime to alum or iron, or a considerable increase in the amount of chemicals, is often effective with such trouble.

At weekly or bi-weekly intervals each filter should be examined. This is best done just previous to washing the filter. The points to be investigated are:

a. The condition of the sand.
b. The rate of washing and the process of washing.
c. The rate of filtration.
d. The operation of the effluent controller.
e. The operation of the loss of head gages.

The filter to be examined should be shut down and the water level lowered below the sand line by opening the drain valve. The general appearance of the *Schmutzdecke* should be noted, and a sample of sand should be taken.

The filter should then be washed. During this process the rate of washing should be measured as explained under "Calibration." Any unevenness in the wash distribution should be noted. The sand should be lifted over the whole area of the filter bed. This can be ascertained by thrusting a thin pole into the filter sand, which should meet no obstruction until the gravel is reached. A cup attached to a stick should be held so as to receive the overflow from the wash-water troughs, and the samples of water so obtained should be examined for any sand which might be carried over.

After washing, the water should again be drawn down to observe the effect. There should be no patches of mud left on the filter sand, although a uniform, thin film of coagulum is not objectionable. The sand surface should be level and free from bumps or hollows. There should be a mark placed on the side of the filter tank at the sand line, and note should be taken as to whether the sand is settling below this mark, which may be due to the sand being washed away, or to settling in the under-drain system. A sample of the sand should be taken and examined for incrustation and change in effective size.

The rate of filtration can be checked as explained under "Calibration." By taking this at intervals during a run the working and accuracy of the rate controller can be checked. The correctness of the loss-of-head gages can be ascertained by measurements of the actual difference in level between the water on the filter and in the effluent pipe.

In connection with the other routine work, occasional turbidity and bacterial tests of the settled water will shed light on the efficiency both of the settling basin and filters. As much work as possible should be thrown on the settling basin, as this prevents clogging of the filters and reduces the amount of wash water required.

Operation of Filters. The ultimate efficiency of the plant depends entirely on the care and proper manipulation of the filters, no matter now perfect the coagulation or sedimentation. The maintaining of a suitable rate of filtration is most important, owing to the fact that the coagulant forms a gelatinous mat on the surface and in the upper part of the sand, which forms the real medium of filtration, and which is broken through by excessive velocities of the water. The maximum rate with alum

coagulation usually is 125,000,000 gallons per acre per day, with iron, 100,000,000 gallons per acre per day, corresponding respectively to 2.0 and 1.6 gallons per square foot per minute. Generally the filter capacity is more than sufficient and a lower rate can be adopted. The load should be distributed among all the units equally, an important point, often neglected.

Each filter unit is provided with a rate controller on the effluent outlet, the purpose of which is to maintain automatically a constant rate of filtration regardless of loss of head. These controllers are provided with an adjustment by which they may be set to filter at any desired rate. If kept clean, and given the care and attention required by any automatic device of this character, they will function properly and do much toward maintaining a uniform distribution of load among the units and preventing the sudden breakings-through of the filter mats, with the consequent pollution of the clear-water basin with raw water. Too often they are neglected to a point where they cease to operate, or are dismantled by the operator, rate control being attempted by manipulating the effluent valves so as to maintain a uniform loss-of-head reading or until the operator feels by some unerring instinct that the right rate of flow is attained. This practice cannot be too severely condemned, and the same can be said of the very general tendency to deprecate other automatic devices and gages about the plant, because they do not operate from the start without attention. Such devices used about a filter plant are very simple compared to those used successfully in other work, and their inoperativeness reflects strongly on the mechanical ability of the attendant. In rate controllers, proper care generally involves keeping bearings and sliding joints lubricated and free from incrustation, orifice openings clean and of full size, and preventing air pockets.

Rate controllers should be calibrated occasionally to see that they are correctly set. To do this, close the influent valve and note the fall in water level over the whole area of the filter unit in half a minute. Repeat several times and from the average drop compute the quantity of water in cubic feet, which, multiplied by 15, gives the rate in gallons per minute. Compare this with the setting of the controller, which correct accordingly. Repeat for various rates and for each filter unit. Check the regulation of the controller by noting the rate, as above, with different heads

over the filter sand, or vary the head by throttling the effluent valve.

Each filter is equipped with a loss-of-head gage, to measure the friction loss through the mat, sand, gravel, and under-drain system. When operating properly, this should be an index to the load distribution among the filters, as the loss of head should increase uniformly for all, and to the time for washing the filter, which should be done whenever the loss of head is not over 8 feet greater than the initial loss of head, pertaining when the filter is put into commission after washing. If any filter shows an excessive loss of head as compared with the rest, under normal operating conditions, it is a sign that the gravel or strainer system is clogged or obstructed.

As generally constructed, the loss-of-head gage consists of two float tubes, one connected with the raw water above the sand, the other with the effluent pipe. The difference in the water levels in these tubes is recorded on a dial by means of floats operating a differential gear. The gage can be adjusted to read correctly by measuring from the tops of the tubes the distance to each water level, obtaining the difference in water levels by subtraction, and setting the pointer of the gage to read correctly on the dial. Gages which operate from the floats by means of wires or cords are easily thrown out of adjustment and should be frequently checked and reset if necessary.

The effluent pipe from each unit should be provided with a sampling cock or pump, so that frequent individual samples can be obtained for bacterial and turbidity tests. Any filter found giving an inferior effluent should be shut down at once, and not used until the cause of trouble has been found and corrected. If the water in the clear-water basin appears cloudy, more alum or iron should be used; if, with the iron treatment, it has a yellow tint, use more lime. A porcelain plate placed in the bottom of the clear well and observed from a dark place will accentuate any cloudiness or discoloration.

It is important that the sand and gravel be kept clean. This can generally be accomplished by washing with sufficient water and pressure. If the wash water is not uniformly distributed, as will occur should some of the strainers become stopped up, certain portions of the sand will accumulate filth indefinitely and become breeding-places for bacteria. Similarly in a poorly designed or

operated filter, mossy growths will form in the gravel and underdrains. Such conditions will manifest themselves on inspection of the filter after washing by slimy, obviously unwashed, patches on the sand surface, which should be followed up by digging into the sand. Furthermore, the filtered water may contain bits of decayed moss, or have a higher bacterial count than the settled water. Under conditions of over-treatment with lime, calcium carbonate will precipitate on the sand grains, causing them to grow in size until they become ineffective for filtering purposes. Dirty sand can be removed, washed, and replaced; sand coated with lime must be replaced with new. Hard washing will remove a proportion of the finer particles of sand, and it is advisable to keep on hand a supply of finer sand and replenish the filters by spreading a thin layer of this over the coarser sand. Clogged-up strainers can be cleaned by immersing in dilute hydrochloric acid until the deposit is dissolved and then washing to remove the surplus acid.

When a filter is operating, silt and coagulum are continually collecting in the upper part of the sand, causing an increasing resistance to the passage of water, until a point is reached at which the pressure of water above the sand is not sufficient to force the rated quantity through the filter. A vacuum is then formed below the sand surface, as the water is running through the lower part of the sand faster than it can pass through the clogged upper portion under the water-head alone, and this vacuum aids in keeping the filter up to its capacity. This decrease in pressure causes dissolved gases to come out of solution and collect at the point of maximum vacuum, forming a film of gas across the filter which effectually stops the passage of water. This gas is partly air and partly carbonic acid, and is further augmented by air drawn into the filter through defective flanges and valve stems in the effluent pipe. If the effluent pipe is closed, the air will rise to the surface in large bubbles, breaking up the mat and forming passages through the sand. The filter must then be washed before again being placed in service.

There is a tendency for scum and foam to collect on the walls of the filters near the water-line and on the wash-water troughs. This is unsightly, and should be cleaned off frequently.

Washing Filters. The method of washing filters depends on the design of the filter, which may be one of three types: the old circular tank type, provided with revolving rakes for agitation;

the concrete unit provided with air agitation; or the most recent "hard-wash" type.

a. Revolving-rake type:

1. Close influent valve and allow water to draw down to top of troughs.
2. Close effluent valve.
3. Open sewer full wide.
4. Open wash-water valve very slowly.
5. While wash water is rising, allow agitating rakes to trail backward slowly.
6. Start agitating rakes forward at 10 to 12 revolutions per minute.
7. When filter is sufficiently washed, start agitator trailing backward and *slowly* close wash-water valve.
8. Close sewer valve.
9. Open influent valve and allow water to come to normal level.
10. Open effluent valve slightly and after about five minutes open fully.

b. Air-agitation type:

1. Close influent valve and allow water to draw down to top of troughs.
2. Close effluent valve.
3. Open sewer fully.
4. Open air valve—(keep air on about 3 minutes).
5. Close air valve and open wash water valve slowly.
6. When filter is sufficiently washed, *slowly* close wash-water valve.
7. Close sewer valve.
8. Open influent valve and allow water to come to normal level.
9. Open effluent valve slightly and after about five minutes fully.

c. Hard-wash type:

1. Close influent valve and allow water to draw down to top of troughs.
2. Close effluent valve.
3. Open sewer fully.
4. Open wash-water valve slowly.
5. When filter is sufficiently washed, close wash-water valve *very slowly.*

6. Close sewer valve.

7. Open influent valve and allow water to come to normal level.

8. Open effluent valve slightly and after about five minutes fully.

As to rate of wash, this should be as high as possible without washing away any sand. To test this, wash the filter thoroughly clean, then with different openings of the wash valve, collect samples of water from the wash troughs in large glass jars. Allow these to stand and note whether any sand settles out. The highest rate at which no sand appears should be used, and can be conveniently gaged by the number of turns the wash valve is open. A pressure gage attached to the wash pipe as it enters the filter furnishes a convenient method of measuring the rate of wash.

Washing should be continued until all the heavy dirt is removed, but *not* until the filter is perfectly clean, as it is desirable to have a film of coagulant jelly about 1/16 inch thick over the entire sand surface to form a mat when starting the filter, and to wash beyond a certain stage requires an excessive amount of wash water. The total time for washing is generally about 8 to 12 minutes per filter.

An inspection of the sand surface after washing forms a good criterion of the rate, length, and distribution of wash. The surface should be covered with a uniform film of jelly as above mentioned. Removing this, the sand should be absolutely clean. The presence of mud uniformly distributed would indicate too short a period of washing or too low a rate. Mud near the sides of the wash troughs denotes that these are too far apart and can be partially remedied by a higher rate and longer period. Isolated mud patches suggest stopped-up strainers, especially if the sand beneath is not clean. Craters of sand are signs of water channels due to vertical stratification, broken strainers, or air pipes. Mud-balls occur with low rates of wash. These and other accumulations of mud should be carefully removed with a long-handled spade.

It is important that the wash valve be opened and especially closed very slowly. This has the effect of leaving the sand stratified horizontally in layers of increasing fineness upward, and therefore in the best condition for filtering.

It is not best to wash all the filters in succession, but this

work should be divided proportionately among the shifts, as this tends toward greater uniformity of the effluent and causes less unbalancing of operating conditions. In small plants, say of three units, washing one filter throws 50 per cent more water into each of the others, which may disturb their operation, especially with a small settling basin or poorly regulating controllers.

Clear-Water Basin. The clear-water basin should be kept scrupulously clean. Hatchways leading into it should be tightly covered; and if necessary to enter it while in use, great care should be used to prevent its pollution in any way. If the pipe gallery is of the open type, *i.e.*, used as or connected with the clear-water basin, the raw-water and sewer pipes should be inspected at least weekly for leaks. The same holds for the fronts of the filter tubs, if forming part of the walls of the clear-water basin.

Laboratory. It would seem almost needless to say that all apparatus, reagents, etc., must be kept perfectly clean, and that all tests must be made with scrupulous care, yet in these particulars the grossest negligence is often found, especially in small plants. The room and furniture should be kept free from dust to prevent pollution of bacterial tests. Reagents should not be allowed to grow stale and must be standardized frequently to insure their correctness. This applies as well to distilled water, which often contains traces of impurities. A good way to test reagents is to run blank analyses with distilled water of known purity and record the results. The stoppers of reagent bottles should never be laid upon the desk, unless upon a clean paper, and the neck and mouth of such bottles should be kept scrupulously clean, and the mixing up stoppers avoided. The reagent should be added very slowly with constant stirring. Glassware, except for bacterial tests, should always be wiped with a clean lintless towel just before use. The work should be laid out so as to secure the best economy of time. Thus if one test involves a lengthy filtration or boiling of the sample, another test can be run while this is in progress. A note-book should be kept containing a dated record of all tests and computations systematically and neatly arranged.

Calibration of Apparatus. In order to adjust the chemical dosage properly, it is necessary that the means of measuring the raw-water pumpage be accurate. Whether this be determined by Venturi meter, weirs, stroke counter, or tachometer, the accuracy

of the device should be tested. If a stroke counter or tachometer is used, the test should be repeated at intervals, as the slippage factor of the pumps changes from time to time. This test is best made by closing the outlet of the settling basin into which the pumps deliver, and measuring the rise in water in the basin and the number of revolutions made by the pumps discharging into the basin, in a given time. Then from the area of the basin and the rise in water level, the pumpage can be calculated in cubic feet, and this quantity multiplied by 7.5 and divided by the number of revolutions gives the gallons pumped per revolution.

Example. A reciprocating pump being tested delivers into a basin 40×80 feet in plan. The duration of the test is 30 minutes, the rise in the basin is 1.83 feet, the number of revolutions made by the pump is $943\frac{1}{2}$.

Area of basin	=	40×80	=	3,200 sq. ft.
Volume pumped	=	3200×1.83	=	5,850 cu. ft.
Gallons pumped	=	5850×7.5	=	43,875 gallons
Gallons per revolution	=	$43875 \div 943\frac{1}{2}$	=	46.502 gal. rev.

In testing centrifugal pumps, the rise should be one foot or less, the water level in starting being six inches below that normally carried in the basin, and, on stopping, six inches above normal level. Centrifugal pumps should be tested at various speeds and a curve showing the relation between speed and capacity should be plotted.

Venturi meters are tested in a similar manner, the computed discharge in gallons being compared with the registered discharge of the meter, the latter being corrected if a discrepancy develops.

The rate of filtration can be checked in a similar manner, by closing the influent valve and measuring the drop in water level for one minute. The area of the filter in square feet multiplied by 0.625 times the drop in inches gives the rate of filtration in gallons per minute. By repeating this test with different losses of head through the filter, the adjustment of the rate controllers can be checked.

By a similar process the rate of washing can be obtained.

The solution tanks and orifice boxes should be calibrated. This is done by first measuring the cubical contents of the tanks, and multiplying this by 7.5 to obtain the capacity in gallons. Then,

with the orifice open to a certain mark, note how far the water level in the solution tank drops in a given time. From this the rating of the orifice can be obtained. The test should be repeated for different orifice openings and a table or curve plotted giving the rate of discharge of the orifice for different openings.

Besides making the above tests, the operator should measure and compute the capacities of all the various units in the plant, and make a permanent record of the results for reference. This should include the ratings of all pumps, capacities of settling basins, filters, clear-water basins, wash-water tank, solution tanks, etc.

Organization. The organization of the force operating a filtration plant depends principally on the size of the plant, to a less extent on whether or not softening is attempted. Small plants connected with public institutions or supplying villages require only a portion of one man's time, who may also act as pumping-station engineer or perform other duties. Plants in small towns, which operate only part of each day, can be managed by one man, with possibly the occasional help of several laborers for cleaning and repairs. The same plant, so situated that, because of lack of storage facilities, it must be run continuously, twenty-four hours per day, must obviously have at least one man per shift.

In towns and cities of moderate size, say 20,000 to 60,000 inhabitants, the force would generally consist of a chemist, assistant chemist, three filter operators, three coagulant house operators, and a janitor and utility man, in all nine men. The chemist would have general supervision of the plant, besides making the chemical and bacteriological determinations. The assistant chemist would assist in the laboratory work and in keeping the records, and would make the necessary tests in the absence of the chemist. The duties of the filter men and the coagulant house operators are obvious, there being one each of these per shift. In smaller plants the two positions can be combined, thereby eliminating three men. The utility man will do janitorial work most of the time, but should be ready to assist wherever required or to replace any of the operators in emergency.

In plants of large size, there is not only a corresponding increase in personnel, but, owing to the complex apparatus used, skilled workmen are required. A superintendent is necessary,

who has entire charge of the plant. There should be at least one chemist and one bacteriologist, either being capable of taking over the other's work. In the absence of the superintendent, the plant should be in charge of the chemist. There would probably

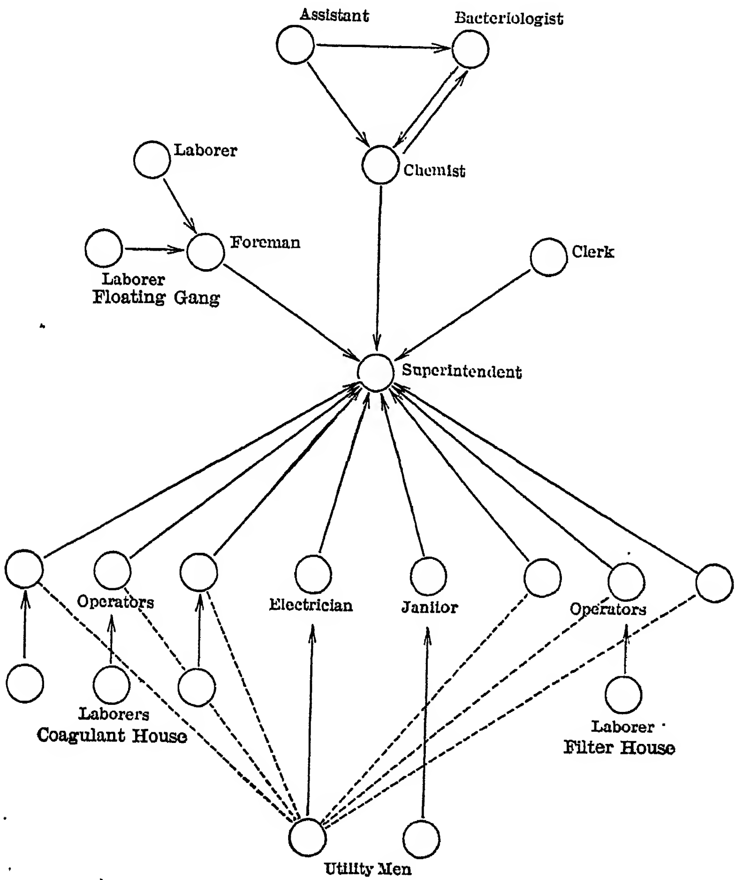


FIG. 89.—Organization Chart for a Large Filtration Plant.

be one foreman and one laborer in the coagulant house, and one filter operator, in each shift. There should be at least one skilled mechanic and electrician, and a foreman with several laborers to look after any outside or repair work, such as cleaning basins, replacing filter sand, etc. A janitor, utility man, and a clerk will also

be required. Such an organization is shown by the chart, Fig. 89.

Cost of Operation. Perhaps the largest single factor affecting the cost of operation of filtration plants is the amount of coagulant used. This varies with the quality of the raw water, and increases greatly when the water is softened. The labor cost increases with the size of plant from the smallest to plants of perhaps 10,000,000 gallons capacity, after which the cost per million gallons decreases. Against the cost of filtering should be charged the cost of pumping the water against the head lost in filtration, which is generally from 10 to 15 feet. The following are typical examples of the cost of filtration in plants of various sizes:

Example No. 1. Cost of Coagulation and Sedimentation at St. Louis, Mo. The treatment consists of coagulation with lime and iron sulphate, followed by sedimentation in large basins. The source of supply is the Mississippi River below the mouth of the Missouri, consequently a very high turbidity prevails much of the time. The average amounts of chemicals used in 1911 were 5.77 grains per gallon of lime and 2.70 grains per gallon of iron sulphate.

Cost of Purification per Million Gallons (1910–1911)

Lime	$1.967
Sulphate of iron	1.969
Unloading	0.094
Operating amd maintenance (labor)	0.378
Repairs	0.030
Water, coal, oil, etc	0.047
Light and power	0.098
Water analyses (chemist's)	0.172
Total	$4.755

The average daily pumpage was about 86,000,000 gallons.

Example No. 2. Cost of Filtration at Harrisburg, Penna. This is a standard type mechanical filtration plant. The pumpage for 1911 averaged 8,205,684 gallons per day. The average amount of coagulant used was 0.7 grain per gallon.

Cost of Purification per Million Gallons (1910–1911)

Coagulant	$1.22
Fuel (low service)	0.86
Supplies	0.28
Materials and repairs	0.36
Oil and waste	0.07
Laboratory	0.43
Labor	2.77
Total	$5.99

Example No. 3. Cost of Filtration at a Typical Small Plant. Daily pumpage, 2,000,000 gallons. Water slightly acid at times, requiring the use of soda ash. Average amounts of coagulant used 0.7 grain per gallon of alum, 0.5 grain per gallon of soda ash.

Cost of Purification per Million Gallons

Alum	$1.25
Soda ash	.86
Fuel (low service)*	.73
Supplies, oil, and waste	.42
Repairs	.07
Labor	2.00
Total	$5.33

Example No. 4. Cost of Purification in a Large Softening Plant. Daily pumpage, 50,000,000 gallons; lime used, 8 grains per gallon; iron sulphate, 1 grain per gallon. Plant is equipped with conveyers, automatic scales, and other labor-saving devices.

Cost of Purification per Million Gallons

Lime	$2.71
Iron sulphate	0.72
Labor	0.69
Material, supplies, and repairs	0.56
Laboratory	0.12
Low-service pumpage *	0.40
	$5.20

* Cost of pumping the additional head lost in the filtration plant.

BARKERVILLE FILTER PLANT

DAILY REPORT

Date. . . . .

Weather . . . .

Hours pumped.	Amount pumped.	Gallons
Alum used	Pounds	Gr/Gal.
Lime used.	Pounds	Gr/Gal.
Filters washed	Time	Minutes
Wash water used.	Gallons.	% of raw

Analyses:	Raw water	Filtered water
Turbidity.	. . . .	. . . .
Color.	. . . .	. . . .
Alkalinity.	. . . .	. . . .
CO_2.	. . . .	. . . .
Bacteria.	. . . .	. . . .
Coli.	. . . .	. . . .

Remarks:

Signed

. . . . Operator

FIG.—90. Daily Report Form for a Small Purification Plant.

Records and Statistics. The records to be kept depend largely upon the size and purpose of the plant. Even in the smallest plants a note-book should be kept in which results of analyses, amounts of water pumped, and chemicals used should be recorded. In any but institutional plants, a daily form similar to Fig. 90 should be filled out, preferably in duplicate, one copy being sent to the water-works office for record and the other being kept on file at the plant. It is convenient to keep these reports on paper of some standard loose-leaf system. The operator should also keep an accurate record of the time of men employed about the plant, material received, and such events as cleaning the basins, renewing filter sand, and the like.

In large plants, especially if municipally owned, more complete records must be kept. These should include:

a. Laboratory note-books.
b. Diary.
c. Time and material-book.
d. Plant invoice and data.
e. Daily report.
f. Annual report.

The laboratory note-books should contain complete data, computations, and results of all tests made in the laboratory. These are best kept in chronological order in books of uniform size and appearance. It may be well to have separate books for physical and chemical water analyses, bacteriological analyses, analyses of coagulants, etc., to prevent interference if several of these are conducted at once, and to render the records more accessible.

The diary is best kept by the superintendent himself, and should contain events of importance in sufficient detail to make it a running history of the plant.

The time- and material-book should contain the time of all employees and a record of all material received. This would contain entries of the amounts and quality of coagulants received, laboratory supplies, packing, oil, light, and steam used, etc.

A book should be kept giving a list of apparatus in the plant, capacities of basins, filters, clear well, ratings of controllers, orifices, etc., for ready reference.

A short form of daily report has already been given. Fig. 91

GROVE CITY WATE

DAILY OPERATION REC

Date	Time	Attend't	Weather	Temperature		River Stage	Water Pumped		Coagulants Used								Wash Water Used		
				Air	R.Water		Raw	Filtered	Lime		Soda		Alum		Hypo		Filters Washed	Time	Amount
				Deg.Fahr.	Deg.Fahr.		U.S.Gall's	U.S.Gall's	Lbs.	Gr/Gal	Lbs.	Gr/Gal.	Lbs.	Gr/Gal	Lbs.	Gr/Gal.		Minutes	Gallons

R WORKS COMPANY

ORD OF FILTER PLANT

From 19 to 19

	Analyses																		Individual Effluents				Remarks
	Raw Water								Settled Water			Filtered Water											
Per Cent	Odor	Turb'ty	Color	Alk'ty	CO_2	Iron	Bacteria	Coli	Turb'ty	Alk'ty	Bacteria	Turb'ty	Color	Alk'ty	CO_2	Iron	Bacteria	Coli	Filter	Turb'ty	Bacteria	Coli	
f R.Water		P.P.M	P.P.M	P.P.M.	P.P.M.	P.P.M	Per C.C.		P.P.M	P.P.M	Per C.C	P.P.M	P.P.M.	P.P.M	P.P.M.	P.P.M.	Per C.C.		No.	P.P.M.	Per C.C.		

Fig. 91.—Operation Report Form.

gives a more elaborate form for use in a large plant. This is arranged to take care of a week's data. It should be made out in duplicate, and with the copy sent to the head office should be included a list of materials and supplies used. and a short account of the week's occurrences at the plant.

The annual report should contain a summary of the year's work. This should include average daily and total pumpages, monthly average turbidity, bacterial count, alkalinity, etc., in the raw, settled, and filtered water; amounts of coagulants used as minimum, average, and maximum monthly values in grains per gallon, and as the total amounts consumed, percentage of wash water used, and other pertinent data. It should also contain a summarized statement of all expenditures, and the itemized cost of filtration per million gallons. The history of the plant for the last year should be briefly given, and the policy for the coming year briefly outlined. In connection with the annual report, attention is called to the form evolved by the committee on filter operation of the New England Waterworks Association.

To care for the letters, bills, invoices, etc., received in connection with the operation of the plant, a filing system of the usual type should be installed, and there should be the usual account-books in which to enter financial transactions.

Automatic Records. Automatic recording devices are coming into vogue in filtration plants. These record graphically, on charts, the indications of meters and gages, and furnish a continuous record of their operation. They are generally attached to the apparatus and furnish the data given in the following list:

Automatic Recorders

Apparatus Whereto Attached	*Data Recorded*
a. Raw-water Venturi meter	Raw water treated
b. Wash-water Venturi meter	Wash water used
c. Wash-water main	Wash-water pressure
d. Loss-of-head gages	Loss of head in each filter
e. Effluent controllers	Rate of filtration per filter
f. Clear-well gage	Depth of water in clear well
g. Coagulant solution tanks	Amount of solution used
h. Coagulant scales	Amount of coagulant used

While all of these records have a certain value, the use of these devices involves considerable care, and the accumulation of charts

soon becomes overwhelming. However, a limited number of automatic recorders are of much value. This is particularly true of the raw-water and wash-water meters. An automatic record of the amounts of coagulant used would be very useful in correcting irregularities of feeding same. This is quite readily accomplished with the various methods of dry feeding described, or with automatic scales, by having an electric contact close at each revolution of the device (or every time the scale discharges), and, by actuating a solenoid, cause a mark to be made on a clock-driven chart. It is less easily done where adjustments are made both in the strength and amount of solution fed to the water. Continuous records of loss of head, rate of filtration, etc., hardly seem necessary in a well-regulated plant.

Electric Alarms and Intercommunication. In all filtration plants there is need for certain electric or automatic alarms. In the small plant it is highly desirable that a device be installed to actuate an alarm in the filter building whenever the water level in the settling basins reaches the point of overflow, as their overflowing results in a waste of water and coagulant. This is simply arranged by means of a float in the settling basins which will close a circuit and ring a bell in the filter building when the water reaches a predetermined height. If the pumping station is separated from the filter plant, a second bell, in series with the first, should be placed there, so that the engineer may reduce the speed of the pumps if the basins threaten to overflow. Similar alarms should be placed on the clear well and the solution tanks, the latter indicating when these have run down, so that they may be replenished before becoming entirely empty.

In large plants there should be a system of intercommunicating telephones between the superintendent's office, laboratory, filter building, coagulant house, and pumping station. If the coagulant house is at some distance from the superintendent's office, it may be advisable to have instruments installed which will indicate the operation of the orifice boxes and other coagulant devices therein. Of course, the alarms on the settling basins and clear well are even more desirable in a large plant than in a small one, as the wastage due to overflowing is correspondingly greater.

The Construction and Interpretation of Graphical Charts. In filter-plant operation and records, graphical charts of a simple type can sometimes be usefully employed. This is particularly

true when it is desired to record data wherein two variable quantities are dependent upon each other, as, for instance, the variation in the turbidity or other quality of the water from day to day; the variation in discharge of a pump at different speeds.

The paper on which such charts are constructed is ruled with horizontal and vertical lines, evenly spaced. These lines are generally arranged in multiples of ten, every tenth line being heavier than the rest, and sometimes every fifth line is also made slightly heavier for ease in reading. Such paper is obtainable, ruled ready for use, at any scientific supply-house.

As an example of the use of this so-called "coordinate" paper, let us suppose that a calibration test has been run on a centrifugal

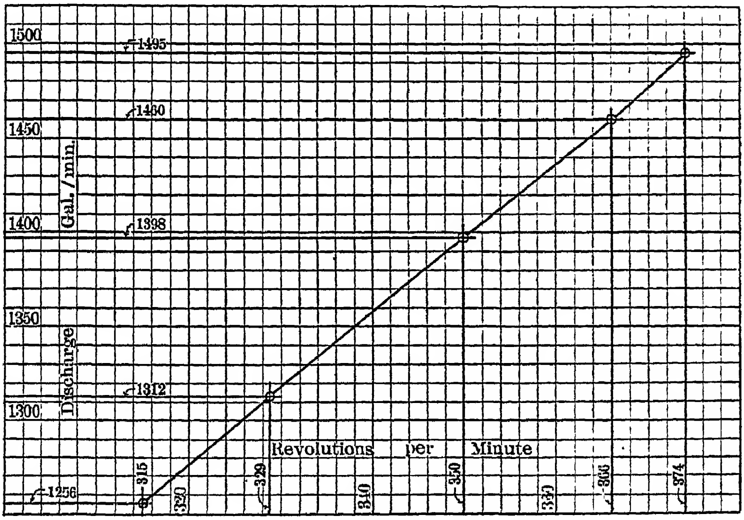


FIG. 92.

pump, discharging against a constant head, in order to determine the discharge in gallons per minute for different speeds. The data obtained may be as follows:

Speed (*in rev. per minute*)	*Discharge* (*in gal. per minute*)
a. 315	1,256
b. 329	1,312
c. 350	1,398
d. 366	1,460
e. 374	1,495

Taking a piece of coordinate paper, Fig. 92, a scale of speeds is laid out horizontally along the lower margin. We will call one of the left-hand vertical lines 300 (revolutions per minute), and assuming each space between verticals to correspond to an increase of two revolutions per minute, the next heavy vertical line, ten spaces above the first, would be marked 320 revolutions per minute, the following one 340, etc. In the same way a scale of discharge capacity is laid off along the left margin, each space between two horizontal lines corresponding to an increase in discharge of ten gallons per minute. Thus starting with a discharge of 1,300 (gallons per minute), at a heavy line near the bottom of the sheet, the next heavy line would be 1,350, the next 1,400, etc.

We are now ready to plot the corresponding values determined in the test. Taking the values (*a*), draw a light pencil line through the vertical corresponding to 315 on the sheet, and another similar line through the horizontal corresponding to 1,256. Where the two lines intersect make a dot, which gives the point on the chart representing the values for speed and discharge for the two corresponding determinations (*a*). In a similar manner find points for (*b*), (*c*), (*d*), and (*e*). A line drawn through these points gives the relation between speeds and discharge for the centrifugal pump, and has the advantage over the tabulated data that intermediate values, not determined by test, can be read off directly from the line or "curve" on the chart. The line thus determined is not always straight, but may be a curve taking a variety of forms. Sometimes, too, the points determined do not lie on any connected line or curve, which results from inaccuracies of the test. In such cases a "curve" is generally drawn approaching the points as closely as possible.

As another example, let it be desired to plot graphically the turbidity of a water for successive days. Let the data be as follows:

Date	*Turbidity* (*in parts per million*)
Jan. 1, 1915	75
Jan. 2, 1915	90
Jan. 3, 1915	116
Jan. 4, 1915	60
Jan. 5, 1915	88

Along the lower margin of a sheet of coordinate paper, Fig. 93, lay

off the time in days, allowing one space for each day. Vertically along the left-hand margin lay off a scale for turbidities, allowing each space between horizontal lines to equal five parts per million. Then plot the turbidities and corresponding dates, as was done in the first case.

A daily graphical record of all the tests made at the plant, while troublesome to make, is very instructive and presents the data in much more comprehensible form than any number of report sheets or monthly averages. A portion of such a record is shown in Fig. 94.

Economy in Operation. It is of course incumbent upon the operator to conduct the plant as economically as possible. Efforts toward this end should be made in the following directions:

a. Careful adjustment of amounts of coagulants to the needs of the water.

b. Elimination of wastes in handling coagulants.

c. Prevention of overflow and leakage of water.

d. Regulation of wash water to the requirements.

e. Reduction of loss of head through plant to a minimum.

f. Profitable employment of labor.

g. Avoidance of waste in materials and supplies.

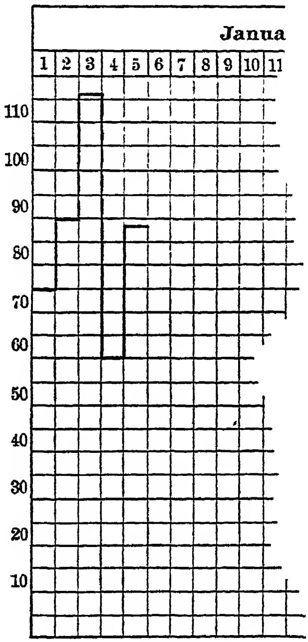


FIG. 93.

The problem of adjustment of coagulants to the conditions of the water so as to obtain most economical results is best attacked along the following line: A sufficient length of time after making the tests and determining upon the amount of coagulant to allow the effect to become noticeable in the basins, a careful inspection is made of the coagulation and the amount of coagulant is readjusted in accordance with the rules already formulated. A sheet of coordinate paper is then arranged, similar to Plate III, with a turbidity scale along the left-hand margin, and a scale for

coagulant in grains per gallon along the lower margin. On this a point is plotted each day, its position being determined by the

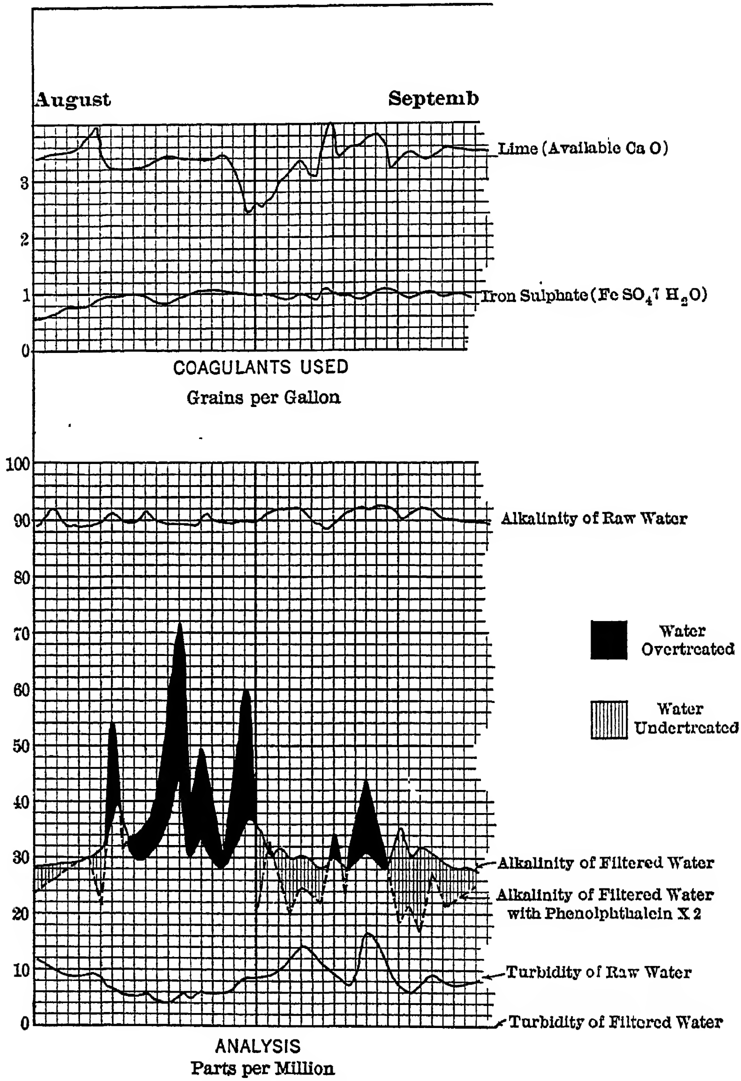


Fig. 94.

value of the turbidity of the water and the grains of coagulant used. After a period of six months there will be some 180 dots

on the sheet. For a given turbidity, there may be several dots, owing to the fact that different amounts of coagulant were used at different times. Presumably, under similar conditions, the dot representing the minimum amount of coagulant for this turbidity could have been used for the other cases where a similar turbidity occurred, and this point can be marked heavily. Proceeding similarly for other turbidities, a series of heavy dots is obtained through which a curve can be drawn, giving a turbidity-coagulant relation for future use, subject, of course to correction as more data are obtained. The economy in shifting the point of application of the coagulant with turbid water has already been considered.

The elimination of waste in the coagulant involves buying this on specifications based on its chemical purity and checking each shipment by an analysis. The shipments received should always be checked as to weight. The care required in handling and preparing solutions of lime and other coagulants has already been considered.

There is often considerable wastage of coagulated and filtered water in a filtration plant. That due to overflowing of the settling basins can be largely prevented by a system of electric alarms, as already described. There frequently occurs a pronounced leakage due to partially closed drain valves in the settling basins and clear well, the remedy for which is obvious; and due to leaks in the walls and floors of these structures. Theoretically the raw water pumped should equal the filtered water delivered, barring slight losses in washing and the addition of coagulant solutions. The raw-water pumpage can be accurately obtained from a Venturi meter or closely approximated from the revolution counters of the pumps. As modern effluent controllers are based on accurate hydraulic principles, the amount of filtered water can be obtained from the rate of filtration or from the revolution counters of the high-service pumps. If the wash water is taken directly from the clear well due allowance must of course be made. If the amount of water filtered is appreciably less than the amount of raw water pumped, either leakage or wasteful operation is indicated.

The amount of wash water and rate of washing should be regulated so as to give the best results. Filters need be washed only when the loss of head indicates the necessity thereof, unless they

become air-bound. Often the amount of wash water used is increased above that required, due to following a fixed schedule in washing, regardless of the condition of the filter. However, the coating and clogging of the sand due to insufficient washing may ultimately incur a greater expense in its removal and replacement than the cost of washing somewhat too frequently.

The effect of properly operating coagulating basins in reducing the wash water required has already been mentioned.

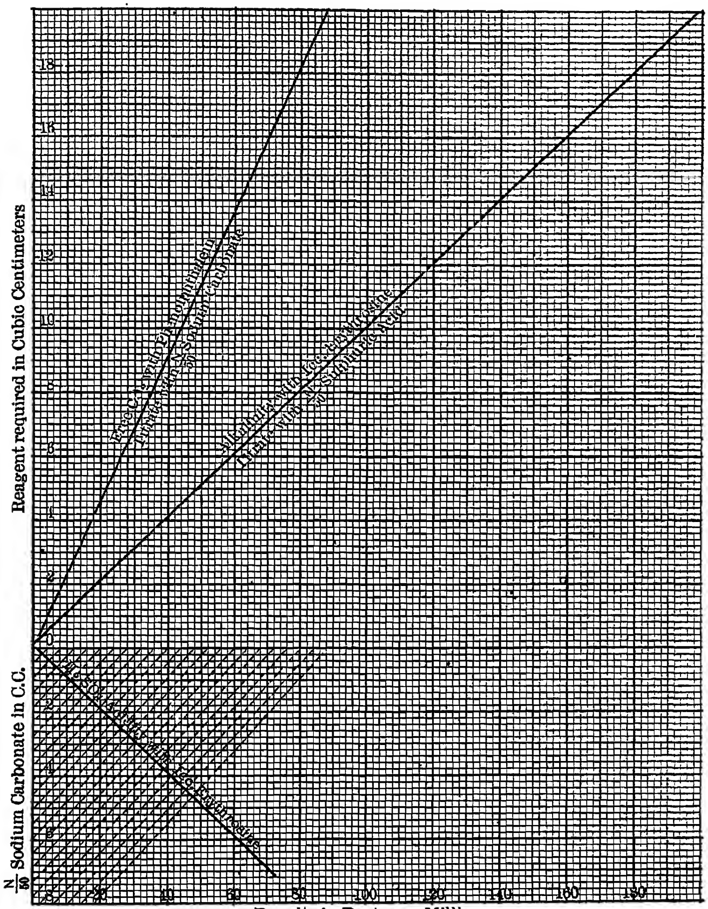
The reduction of loss of head through the plant is accomplished chiefly by keeping the clear well water level high. This reduces the total head against which the high-service pumps must operate and effects a reduction in fuel cost.

The profitable employment of labor and economy in materials and supplies must be left to the executive and economic ability of the man in charge of the plant.

General Remarks. The attitude of the public toward filtration in towns where a plant has just been installed is often one of skepticism. This feeling is sometimes augmented through derogatory statements made by doctors of the "old school," high-school professors, and others who know nothing of the process, but whose utterances carry weight because of their supposed scientific attainments. For purely commercial reasons, venders of bottled mineral waters, etc., will occasionally badly misquote filter statistics. The best way to overcome this tendency is to keep the plant at all times open to and in a presentable condition for visitors, and to induce as many of the townspeople as possible to come and see it. The working of the plant should be explained to visitors, and it is well to have on hand diagrams which will assist in explaining this clearly. In some large plants descriptive pamphlets are given to visitors.

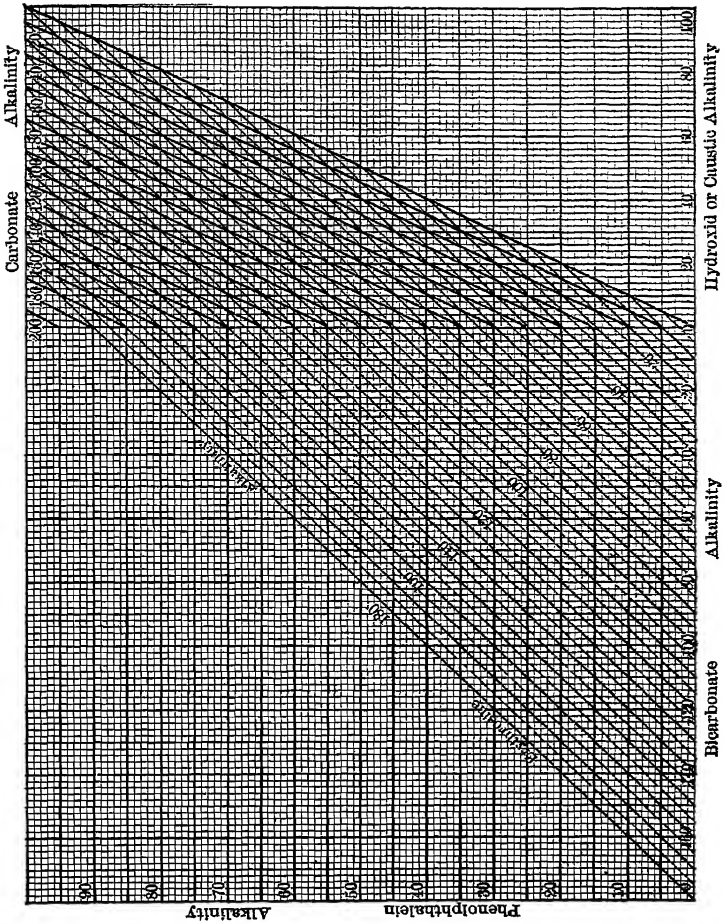
The operator should feel himself under moral responsibility to furnish at all times a hygienically safe water, this duty transcending all others. This is especially true because any return from a pure to an impure water, even for a short time, is almost certain to be followed by an epidemic of intestinal disease in the community, regardless of the fact that the same water had been used with immunity for years before filtration was started.

PLATE I.



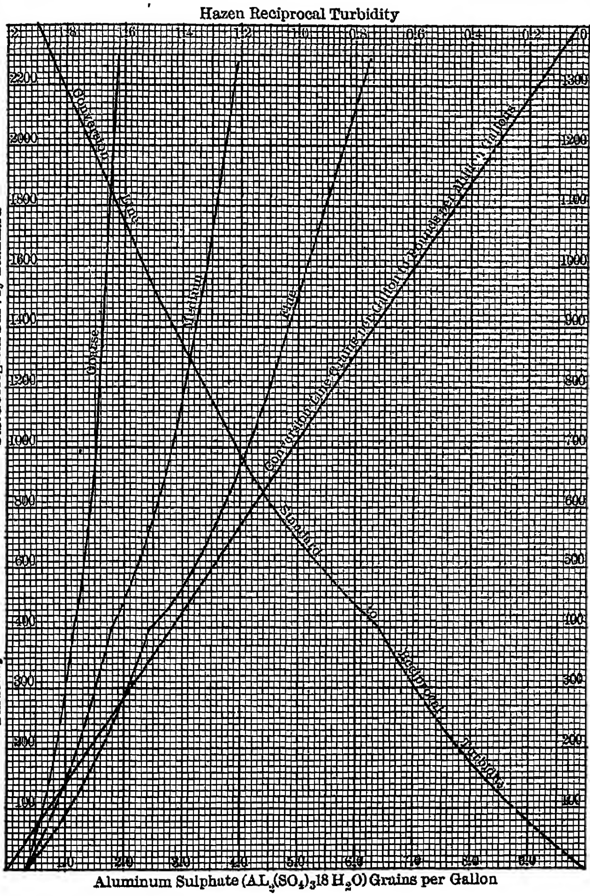
Graphical Results for Tests of Alkalinity, Acidity, and Carbonic Acid.

PLATE II.



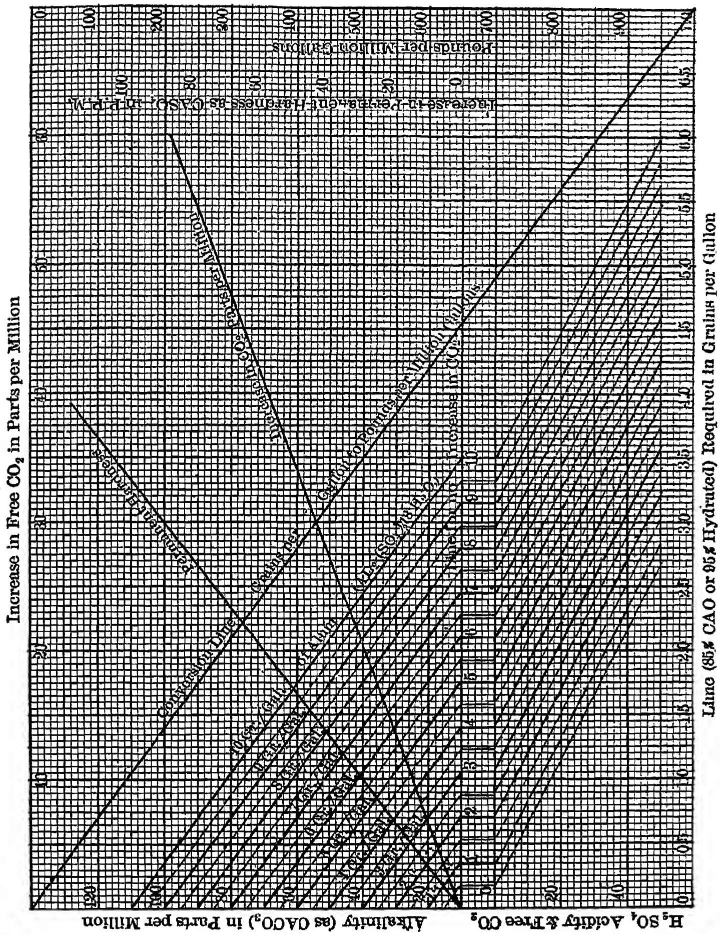
Graphical Determination of Carbonates, Bicarbonates and Hydroxids.

PLATE III.



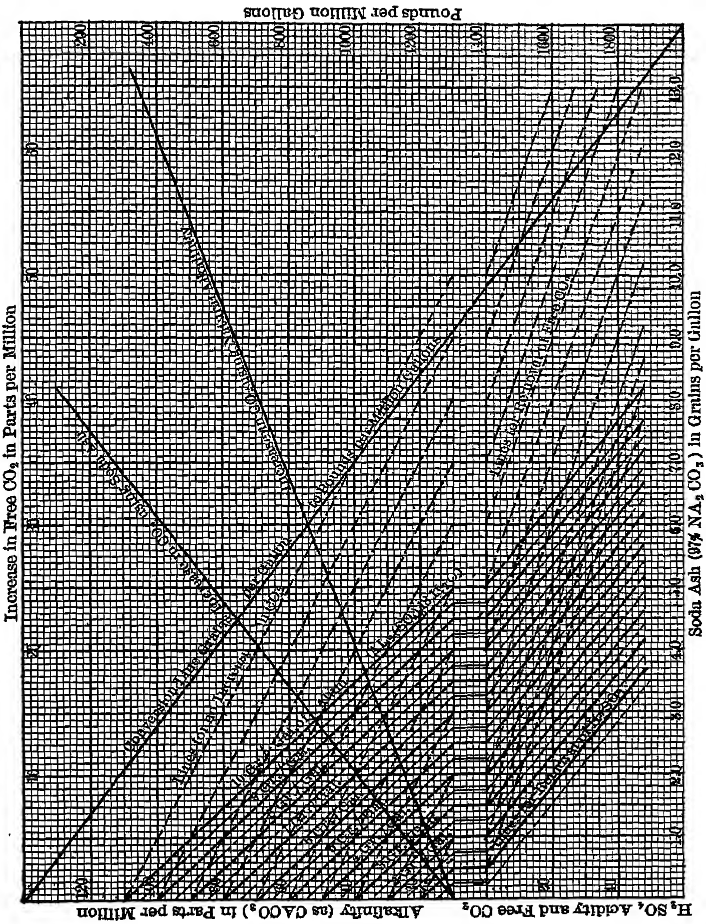
Amounts of Aluminum Sulphate Required for Various Turbidities.

PLATE IV.



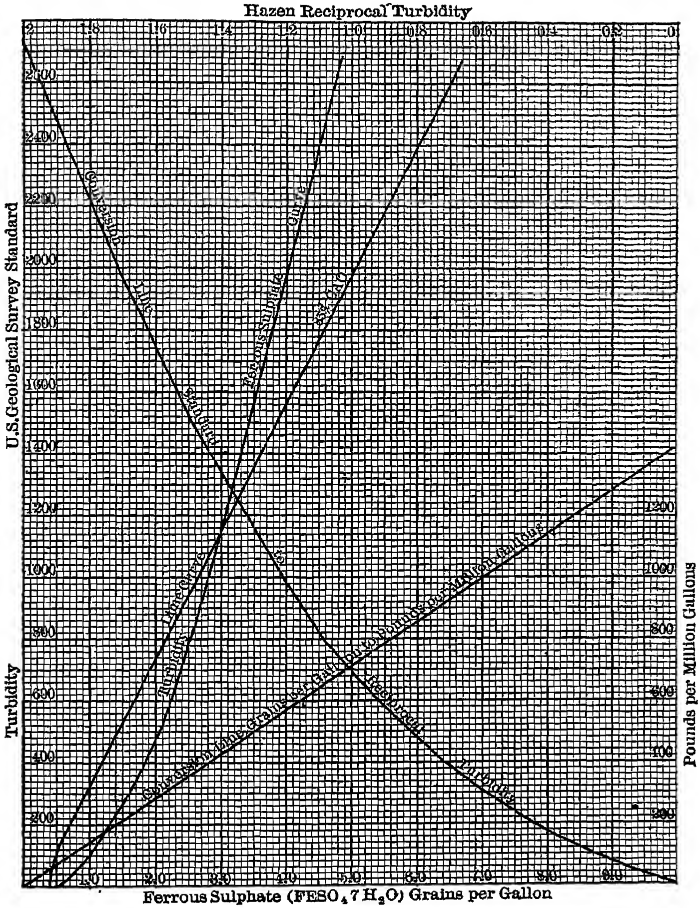
Coagulation with Aluminum Sulphate and Lime.

PLATE V.

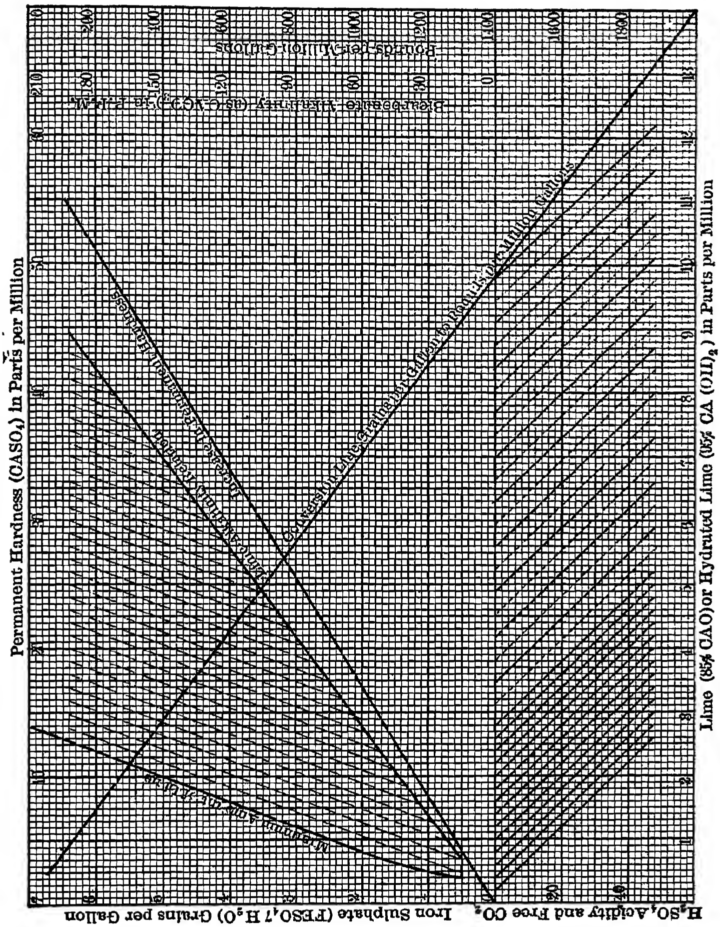


Coagulation with Aluminum Sulphate and Soda Ash.

PLATE VI.

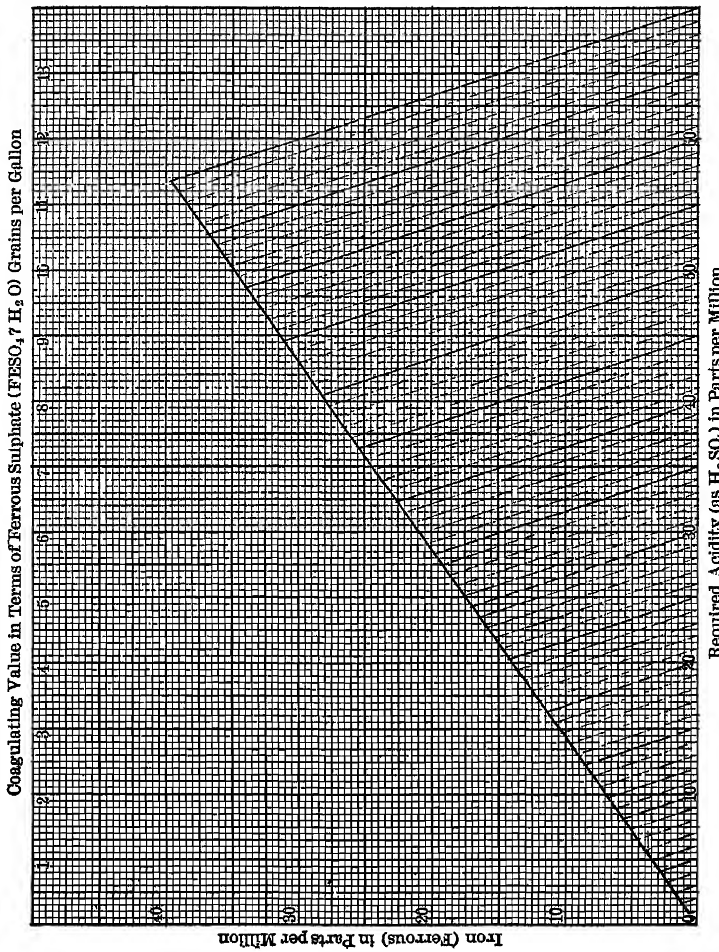


Amounts of Ferrous Sulphate Required for Various Turbidities.



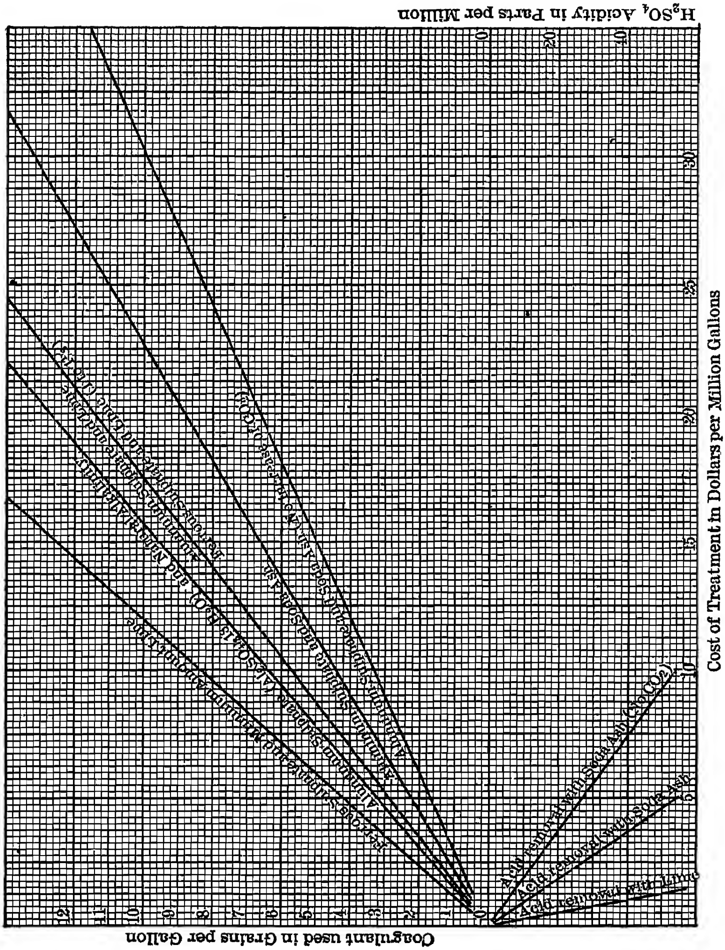
Coagulation with Ferrous Sulphate and Lime.

PLATE VIII.



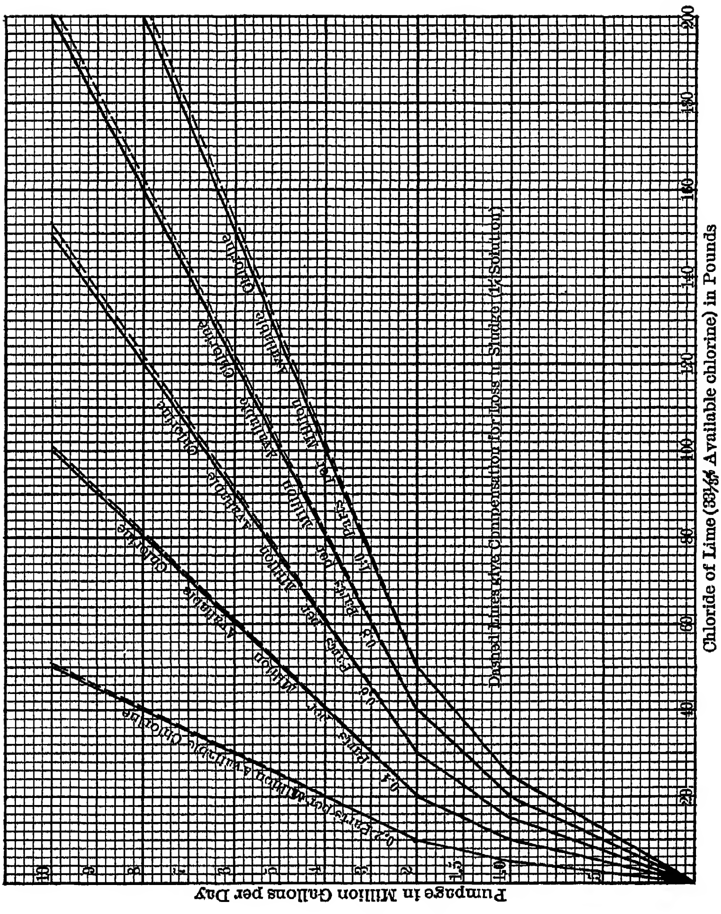
Proportions of Iron and Acidity for Natural Coagulation.

PLATE IX.



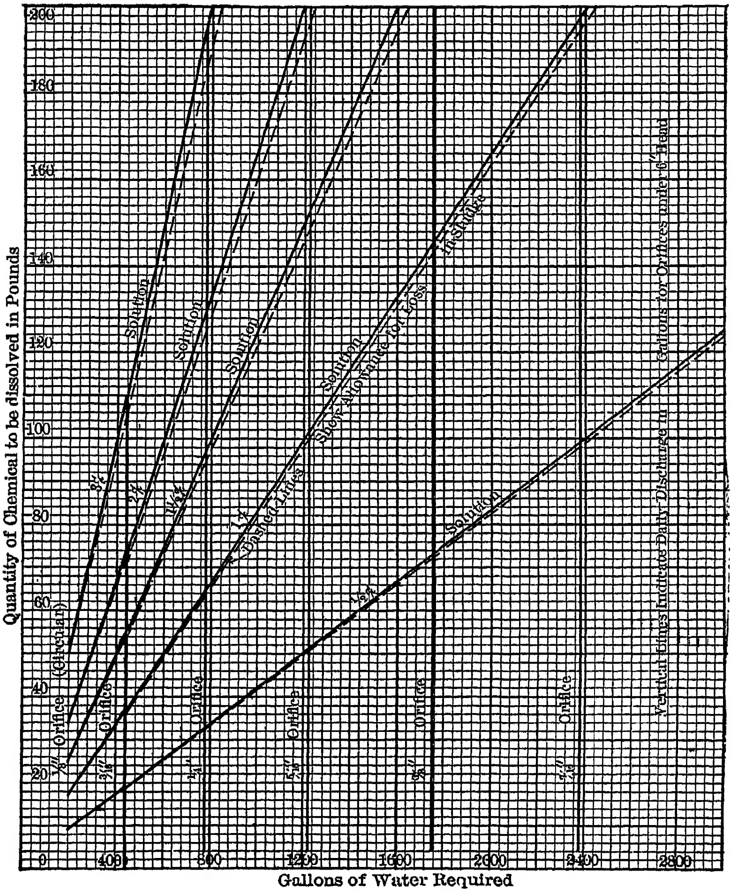
Cost of Coagulation by Various Methods.

PLATE X.



Chloride of Lime Required for Various Strengths of Solution and Rates of Pumpage.

PLATE XI.



Ratio of Water Required to Amount of Chemicals Used to Make Various Strengths of Solution (Also the Daily Discharge of Orifices of Various Sizes).

APPENDIX A

ANALYSIS OF COAGULANTS

Lime. *Determination of Per Cent Calcium Oxid (CaO).* Weigh out 0.28 gram of the sample on an accurate balance. Place in an Erlenmyer flask exactly 100 cc. of 10 per cent cane-sugar solution made with cold, freshly boiled distilled water. Add the weighed sample of lime to this and shake until no further solution is taking place. Do not allow any lime to stick to the sides of the flask. Filter through a dry filter and titrate 50 cc. with $\frac{n}{10}$ sulphuric acid (H_2SO_4), with phenolphthalein indicator. The amount of acid solution required in cc. multiplied by 2 gives the per cent of available calcium oxid. As prolonged shaking may be required, a shaking machine is desirable.

Soda Ash. Dissolve 0.53 grams of the sample in boiled distilled water and make up to 100 cc. Titrate 50 cc. with $\frac{n}{10}$ sulphuric acid (H_2SO_4), using methyl orange as an indicator. The number of cubic centimeters of acid required multiplied by 2 gives the per cent of water soluble soda ash.

Aluminum Sulphate.

a. Total Aluminum Oxid (Al_2O_3). Weigh out one gram of the sample and dissolve in 100 cc. of distilled water. Add 7 to 8 cc. of ammonium chlorid (NH_4Cl), heat to boiling and precipitate the aluminum as hydroxid by adding sufficient ammonium hydroxid (NH_4OH) to render solution slightly, but distinctly alkaline. Allow solution to stand several hours at near boiling temperature until precipitate has all settled out, keeping the solution alkaline with ammonium hydroxid. Decant the clear liquid through a filter, wash the precipitate several times with hot water, which likewise pour through the filter; finally bring the precipitate on the filter and wash several times

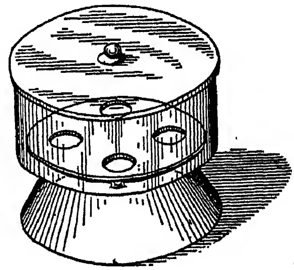


FIG. 95.—Desiccator.

with hot water. Place filter paper and contents in a porcelain or platinum crucible, heat slowly over a Bunsen flame, gradually increasing the heat, and finally ignite for 10 minutes over a blast lamp. Cool the crucible in a desiccator and weigh. An ashless filter paper should be used and crucible should be weighed before the test. The weight in grams times 100 gives the Al_2O_3 in per cent.

b. Total Sulphate (*as* SO_3). Weigh out 1.0 gram of the sample and dissolve in 200 cc. of distilled water. Acidify with concentrated hydrochloric acid (HCl), bring to boiling and precipitate the sulphate with a slight excess of barium chlorid (10 per cent), added slowly with constant stirring. Continue boiling until all the precipitate has settled out (about 10 minutes). Allow the solution to stand and cool at least 4 hours. Decant, filter, and wash as under *a*, using a double filter paper. Dry and ignite the filter paper and contents in a weighed crucible over a Bunsen burner, keeping crucible and contents at dull redness for 10 minutes. Cool and weigh. The weight in grams multiplied by 34.2 gives the per cent SO_3.

Ferrous Sulphate.

a. Total Iron. Dissolve 1.0 gram of the sample in 50 cc. of distilled water and immediately add 15 cc. of concentrated sulphuric acid (H_2SO_4). Dilute to 200 cc. with distilled water and titrate with potassium permanganate solution (see below), until a pink color appears. The number of cc. permanganate solution used gives the percentage of iron in the ferrous sulphate.

Permanganate Solution. Dissolve 6 grams of chemically pure potassium permanganate in a little less than a liter of water. Weigh out exactly 0.7 gram of chemically pure ferrous ammonium sulphate and place it in a beaker. Add 50 cc. of distilled water and 15 cc. of concentrated sulphuric acid. Dilute to 200 cc. and titrate with the permanganate solution until a pink color appears. Ten cc. of the permanganate solution should be required. If less is required, dilute the solution slightly and repeat the test until the correct strength is obtained.

b. Total Sulphate (*as* SO_3). Weigh out 1.0 gram and dissolve in 100 cc. distilled water. Add a few drops of concentrated hydrochloric acid and about 8 cc. of ammonium chlorid (about 1 to 4). Heat to boiling and add a slight excess of barium chlorid

(10 per cent), to precipitate the sulphate as barium sulphate. Keep near boiling point for several hours until all the precipitate has settled out. Cool and decant the clear liquid through double filter paper, wash the precipitate several times with hot water, pouring the wash water through the filter. Finally empty the precipitate on the filter paper and wash several times with hot water. Dry the precipitate and filter paper in a crucible over a Bunsen flame and finally ignite, keeping crucible at dull redness for 10 minutes. Cool and weigh. The weight in grams multiplied by 34.2 gives the per cent SO_3.

Bleaching Powder (Penot Method). Weigh out 7.17 grams and place in a mortar. Add a little water and rub the mixture into a smooth cream, add more water, stir and allow to settle; pour the solution into a liter flask. Mix the remaining sediment with more water, pour into flask and repeat until every particle of powder has been transferred from the mortar to the flask. Fill the flask with distilled water to the liter mark, shake thoroughly, and draw off 50 cc. of the liquid into a beaker. Titrate with $\frac{n}{10}$ alkaline arsenite solution, until a drop of the mixture taken out with a glass rod gives no blue color with prepared starch paper. The number of cc. of arsenious solution used gives the percentage of available chlorine.

APPENDIX B

STANDARD SOLUTIONS

Distilled Water. The purity of distilled water for use in the preparation of standard solutions may be verified by the following tests:

a. **Ammonia or Ammonium Compounds.** Add 10 drops of Nessler solution to 50 cc. of the water. No change of color indicates freedom from ammonia or ammonium compounds.

b. **Chlorids.** No change in color or precipitate on adding a few drops of nitric acid followed by silver-nitrate solution to a 50 cc. sample indicates absence of chlorids.

c. **Sulphates.** Add ¼ cc. of hydrochloric acid and a small amount of barium chlorid to 100 cc. of the water. If no precipitate appears in 12 hours, sulphates are absent.

d. **Nitrates.** Pour 5 cc. of diphenylamine solution into a test tube and add 10 cc. of the water. If no blue color appears at contact surfaces, nitrates are absent.

e. **Residue on Evaporation.** There should be no residue on evaporating 100 cc. of the water to dryness on a water bath.

f. **Heavy Metals and Calcium.** There should be no change on treating 100 cc. with hydrogen sulphid water, ammonia water, ammonium sulphid or ammonium oxalate solution.

g. **Organic or Oxidizable Matter.** Heat 100 cc. of the water to which 1 cc. of strong sulphuric acid has been added to boiling. Add a drop of potassium permanganate and boil three minutes. The pink color should persist.

h. **Neutrality.** Water should be pink to a drop of erythrosin, but color should be discharged by a drop of sulphuric acid.

Sodium Carbonate, Tenth Normal Solution. Heat 10 grams of *chemically pure* sodium bicarbonate in a weighed porcelain dish over a Bunsen burner for about thirty minutes, stirring it with a platinum wire. The dish should be heated to a dull red, care being taken not to *fuse* the bicarbonate. Allow the dish and contents to cool in a desiccator. (This is a two-champered glass dish with cover, the lower compartment containing calcium chlorid, which

keeps the air within the dish absolutely dry. See Fig. 95.) When cool, weigh dish and contents. Then reheat to dull redness, cool in desiccator as before, and reweigh. If there has been any loss in weight, reheat, cool, and reweigh. Continue this process until weight remains constant. When cool, weigh out exactly 5.3 grams on an accurate balance and place in a glass vessel, adding 300 cc. of hot (not boiling) water. This will dissolve the sodium carbonate. When cool pour into a glass-stoppered liter graduate and make up to the liter mark by rinsings of the glass vessel with distilled water. Insert the stopper, shake the liter graduate thoroughly, and transfer the contents into a glass-stoppered reagent bottle. Needless to say, after weighing out the 5.3 grams and placing them in the glass vessel or beaker, *no* stirring rod can be introduced to aid solution, and care must be taken that not a drop is spilled in transfer to the graduate. The graduate should be filled to the liter mark only after contents have cooled to the temperature marked on the graduate (generally about room temperature.) In transferring the normal solution to the reagent bottle, the latter should first be rinsed out with some of the solution.

This is the fundamental standard solution from which the others are prepared. As it does not keep well, an $\frac{n}{20}$ sulphuric-acid solution should be prepared from it (see below) and kept as a standard against which to check the other acid and alkali solutions from time to time.

Sodium Carbonate ($\frac{n}{50}$ = one-fiftieth normal). Measure out 200 cc. of the tenth normal solution into a liter graduate with a burette and make up to one liter with distilled water. Shake well and transfer to a reagent bottle, using the customary precautions.

Sulphuric Acid ($\frac{n}{50}$ = one-fiftieth normal). Pour 1 cc. of pure concentrated sulphuric acid into a liter of distilled water. Insert stopper in graduate and shake thoroughly. Measure out 50 cc. of the $\frac{n}{50}$ sodium carbonate with a pipette, heat to boiling and titrate with the sulphuric-acid solution, using methyl orange as an indicator. Dilute and retest until exactly 50 cc. of the sulphuric-acid solution are required. Transfer to a reagent bottle, using customary precautions.

Sulphuric Acid ($\frac{n}{20}$ = one-twentieth normal). Pour 2 cc. of pure sulphuric acid into a liter of distilled water. Shake thoroughly. Measure out 25 cc. of the $\frac{n}{50}$ sodium carbonate with a pipette and titrate at boiling with the sulphuric-acid solution, with methyl

orange as indicator. Adjust by dilution until 25 cc. of the carbonate are neutralized by exactly 10 cc. of the sulphuric-acid solution.

Hydrochloric Acid, Normal Solution. Weigh out 181 grams of 20.2 per cent chemically pure hydrochloric acid (specific gravity = 1.10), and pour slowly into 400 cc. of distilled water. Allow to cool and transfer to a liter graduate. Rinse original containing vessel repeatedly with distilled water, pouring rinsings into graduate. Make up to liter graduation with distilled water, stopper and shake well. This gives an approximately normal solution. For greater accuracy titrate with normal sodium carbonate, using methyl orange as indicator, and adjust acid solution until equal amounts neutralize each other.

Hydrochloric Acid ($\frac{n}{20}$ = one-twentieth normal). Measure out 50 cc. of the normal acid solution into a liter graduate containing several hundred cc. of water with a burette and make up to the liter mark with distilled water. Stopper and shake thoroughly and transfer to a reagent bottle in the usual manner.

Hydrochloric Acid (1:1 solution). Pour a measured quantity of the chemically pure hydrochloric acid, *very slowly*, into an equal amount of distilled water. *Use extreme caution* to prevent spattering of the acid or overheating the water.

Sodium Hydroxid, Normal Solution. Dissolve 50 grams of chemically pure caustic soda (NaOH) in a liter of boiled distilled water, after first washing the sticks of soda in CO_2 free water, to remove carbonates from surface. Shake well and titrate 25 cc. with normal hydrochloric acid, using methyl orange as an indicator. Adjust by dilution until equal quantities of each solution neutralize.

Sodium Hydroxid ($\frac{n}{20}$ = one-twentieth normal). Measure out 50 cc. of the normal solution into a liter graduate and make up to one liter with distilled water. Stopper graduate, shake well, and transfer to reagent bottle.

Phenolphthalein (Indicator). Dissolve 1 gram of the powder in 200 cc. of 50 per cent alcohol.

Erythrosin (Indicator). Dissolve $\frac{1}{10}$ gram of the sodium salt in one liter of distilled water.

Methyl Orange (Indicator). Dissolve 1 gram of the powder in one liter of distilled water. This indicator reacts red with acids and yellow with alkaline solutions.

Potassium Permanganate Solution. Dissolve 5 grams of the pure crystals in a liter of distilled water.

Potassium Sulphocyanid Solution. Dissolve 20 grams of the pure salt in a stoppered liter graduate with distilled water to the liter mark. Shake thoroughly.

Soda Reagent. Using the normal solutions of sodium hydroxid and sodium carbonate described above, measure out 50 cc. of each solution into a liter graduate and fill to the liter mark with distilled water.

Iodin Solution ($\frac{n}{10}$ = one-tenth normal). Dissolve 12.7 grams of chemically pure iodin and 18 grams of chemically pure potassium iodid in about 25 cubic centimeters of cold distilled water, transfer to a liter graduate, rinsing dissolving vessel into same repeatedly, and make up to one liter with distilled water. Shake well and transfer to a dark-colored reagent bottle. Keep in a dark, cool, place.

Alkaline Arsenite Solution ($\frac{n}{10}$ = one-tenth normal). Dissolve 4.95 grams of the purest sublimed arsenious oxid reduced to powder in about 250 cc. of distilled water in a flask, and add about 20 grams of pure sodium carbonate. The mixture needs warming and shaking for some time in order to dissolve completely; when this is accomplished, it is diluted, cooled, and transferred to a liter graduate. The flask is rinsed several times into the graduate, and the solution is made up to the liter mark.

Test the solution by putting 20 cc. into a beaker with a little starch solution and titrate with the iodin solution, using a burette, until the blue color appears. Exactly 20 cc. of iodin solution should be required.

Starch Solution (Indicator). Mix one part of clean potato starch with cold water into an emulsion, gradually pour in from 150 to 200 times its weight of boiling water, and boil several minutes. Allow the solution to settle and use only the clear portion, a few drops sufficing for each test. The solution may be preserved by adding a few drops of chloroform and keeping it in a stoppered bottle.

Starch Paper (Indicator). Mix a small amount of the starch solution with a few drops of potassium iodid solution on a dish and soak strips of pure filter paper therein. Use while still damp, as it is then most sensitive.

Nessler Solution.* Dissolve 50 grams potassium iodid in a minimum quantity of cold water. Add a saturated solution of mercuric chlorid until a slight but permanent precipitate persists. Add 400 cc. of 50 per cent solution of potassium hydrate, made by dissolving the potassium hydrate and allowing it to clarify by sedimentation before using. Dilute to one liter, allow to settle and decant.

* "Standard Methods of Water Analysis," Am. Pub. H. Assoc.

APPENDIX C

SPECIFICATIONS FOR LIME, SODA ASH, AND ALUMINUM SULPHATE. USED BY THE WATER DEPARTMENT, COLUMBUS, O.*

Lime. All lime furnished under this contract shall be the best quality of fresh-burned, fat lime, crushed or ground so that no lumps shall be greater than 2 inches in any dimension.

The lime shall be delivered in tight box cars, loaded in bulk; especial care shall be exercised to close all openings by which lime might sift out, and to prevent the circulation of air and the admission of moisture.

The lime shall be delivered at a uniform rate of not less than 40 tons per week, or at such increased rate, not to exceed 125 tons per week, as shall be directed.

The percentage of water soluble calcium oxid in each car-load lot of lime delivered will be determined from the analysis of a composite sample collected on its arrival at the water-purification works.

For any car-load lot containing 88 per cent of water soluble calcium oxid the city will pay to the contractor the price per ton stated in the proposal.

It is hereby agreed that the city shall pay a bonus of 1½ per cent of the contract price per ton for each 1 per cent by which the water soluble calcium oxid in any car-load lot delivered shall exceed 88 per cent, and shall deduct a penalty of 1½ per cent of the contract price per ton for each 1 per cent by which the water soluble calcium oxid in any car-load lot shall be less than 88 per cent.

If, in any car-load lot, the material as delivered shall contain less than 82 per cent of water soluble unslacked calcium oxid, it will be rejected and shall be removed by the contractor at his own expense, and the cost of unloading the material from and reloading into the car shall be deducted from the amount payable to the contractor under the terms of this contract.

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* Courtesy of Mr. Charles P. Hoover, chemist in charge.

The car-load lot as a unit will be used as the basis of accounting for determining the amount payable to the contractor.

Soda Ash. The soda ash shall be that known as 58 per cent light soda ash and shall contain not less than 98 per cent of pure sodium carbonate. The material shall be in dry, powdered form, shall contain no large lumps or large crystals, shall be free from chips and other foreign matter, and not more than 0.5 per cent shall be insoluble in cold distilled water.

The material shall be delivered at a uniform rate of not less than 20 tons per week, or at such increased rate, not exceeding 90 tons per week, as shall be directed.

The soda ash shall be packed in duck sacks to be furnished by the city, but the contractor shall furnish the twine. Each sack shall contain not less than 98 nor more than 102 pounds of the material.

The contractor shall handle the bags with care, and for each sack which is delivered to him in good condition, and which is damaged, other than by ordinary wear and tear, or which is lost and not returned to the city, the contractor shall pay the sum of 20 cents, the same to be deducted from the amounts payable to him under this contract. Any bags received by the contractor in a condition unsuitable for refilling shall be set aside and returned to the city. The material shall not be packed when in condition to damage the sacks.

Each car-load lot of material will be analyzed on delivery, and the acceptance of the lot will be determined by the amount of pure sodium carbonate and of insoluble matter shown by this analysis to be present.

If the material in any lot shall contain less than 98 per cent of pure sodium carbonate, or more than 0.5 per cent of insoluble matter, it will be rejected, and shall be removed by the contractor at his own expense, and the cost of unloading and reloading the material shall be deducted from the amounts payable to the contractor on this contract.

The car-load lot as a unit shall be the basis of accounting for determining the amounts payable to the contractor.

Sulphate of Alumina. The material shall be that known as basic sulphate of alumina, containing no free acid. It shall be crushed into small lumps ranging in size from 0.5 inch to 2½ inches, and shall be free from chips and other foreign matter. It

shall contain not less than 17 per cent of available water soluble alumina, Al_2O_3, and of this alumina content there shall be at least 3 per cent of its weight in excess of the amount theoretically required to combine with the sulphuric acid present. The material shall contain not more than 0.5 per cent of matter insoluble in cold distilled water.

Sulphate of alumina shall be shipped, unsacked, in tight box cars; the cars shall be thoroughly cleaned before loading, the door openings shall be boarded up to a suitable height, and all openings by which the material might waste shall be carefully closed.

Each car-load lot of material will be analyzed, on delivery, and the acceptance of the lot will be determined by the amount of alumina and of insoluble matter shown by this analysis to be present.

If the material in any car-load lot as delivered fails to meet these specifications it will be rejected and shall be removed by the contractor at his own expense, and the cost of unloading and reloading the material shall be deducted from the amounts payable to the contractor under this contract.

The car-load lot as a unit shall be the basis of accounting for determining the amounts payable to the contractor.

APPENDIX D

WEIR TABLE

Giving Flow in Gallons per Minute Over a Weir 12 Inches Wide

Depth, in Inches	Gallons, per Minute	Depth, in Inches	Gallons, per Minute	Depth, in Inches	Gallons, per Minute
1	36	4¾	375	8½	900
1¼	50	5	405	8¾	939
1½	66	5¼	436	9	979
1¾	84	5½	468	9¼	1,020
2	102	5¾	500	9½	1,062
2¼	122	6	533	9¾	1,104
2½	143	6¼	567	10	1,147
2¾	165	6½	601	10¼	1,190
3	188	6¾	636	10½	1,234
3¼	212	7	672	10¾	1,279
3½	237	7¼	708	11	1,323
3¾	263	7½	745	11¼	1,369
4	290	7¾	783	11½	1,414
4¼	317	8	821	11¾	1,461
4½	346	8¼	860	12	1,508

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